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The Optical Surfaces of Descartes and Huygens*

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I. CARTESIAN OVALS

IF we start with the definition of optical path, the product $n_1 l_1$ of the refractive index of the medium and the distance the pencil of light travels in the medium, and find that this is the distance in empty space that light would travel in the same time that is required to travel a distance l_1 in medium of index n_1, and then recall the general principle of the stationary path, $\delta \Sigma nl = 0$, we have the basis for the early definition of an aplanatic surface. We may be concerned with reflection or refraction, but, for the present at least, with only one surface, so the equation $\delta \Sigma nl = 0$ becomes $n_1 l_1 + n_2 l_2 = \text{const}$. In other words, the problem is to find a surface whose distances r_1 and r_2 from an object-point O and the corresponding image-point I satisfy the relation $n_1 r_1 + n_2 r_2 = \text{const}$.

The problem has been known in this form for a long time, and has had the attention of almost every prominent figure in the field of optics. Descartes actually arrived at the general solution in his *Ovals*, and spent much time computing surfaces and not a little money trying to construct them. His final conclusion seems to have been that practically aspheric surfaces are out of the question. While that conclusion has since been quite generally accepted, it has been challenged at least twice, by those who felt that molded glass surfaces could be made satisfactorily, and more recently by those interested in the possibilities of the newer plastics. There are also other reasons why the problem in some form or other has periodically appeared as though it were always modern. Yet Huygens may, with reason, be said to have made the final remark on the subject.

The equation, $n_1 r_1 + n_2 r_2 = \text{const.}$, is sufficient to describe the whole family of curves known as *Cartesian ovals*. It is often believed that the interest of Descartes in these curves was quite independent of any optical properties. However, we have in Book II of *La Geometrie* such captions as "La propriété de ces ovales touchant les reflexions et les refractions," and there is evidence outside of his own writings that his interest was not purely mathematical. The mathematical treatment of the general equation is far more elaborate than the optical problem requires, since the constants of the optical problem usually have rather limited ranges. Because the application to single optical surfaces is the chief matter under discussion, only the restricted mathematical portion is to be considered here.

The equation $n_1 r_1 + n_2 r_2 = \text{const.}$, is often written in the form

$$n_1 r_1 + n_2 r_2 = n_0 c, \tag{1}$$

where c is the distance between object-point and

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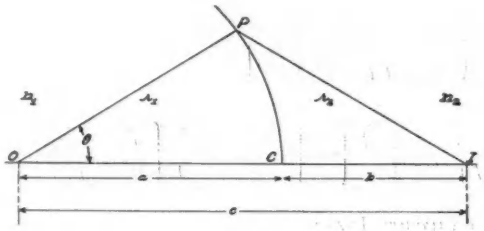


FIG. 1.

image-point. The polar equation of the curve then comes quite readily (see Fig. 1). Let O and I be the fixed points, and let $OI=c$, $OP=r_1$,

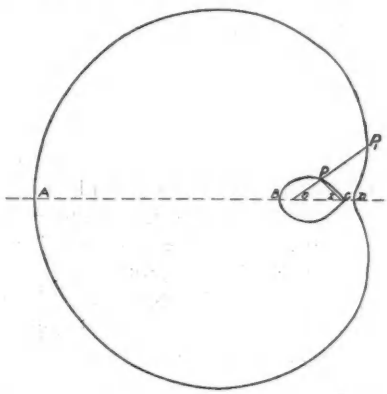


FIG. 2.

$IP=r_2$, $OC=a$, $IC=b$, and $\angle IOP=\theta$. Then $r_2^2=r_1^2+c^2-2r_1c\cos\theta$. But $n_2^2r_2^2=(n_0c-n_1r_1)^2$. Therefore, $r_1^2-2r_1c\cos\theta+c^2=(n_0^2c^2-2n_0n_1r_1c+n_1^2r_1^2)/n_2^2$, or

$$r_1^2-2r_1c\left(\frac{n_0n_1-n_2^2\cos\theta}{n_1^2-n_2^2}\right)+c^2\frac{n_0^2-n_2^2}{n_1^2-n_2^2}=0. \quad (2)$$

This is a common general form.

If, for the moment, we write this as $r_1^2-2r_1\Omega+\Phi=0$, we have the values $r_1=\Omega\pm(\Omega^2-\Phi)^{\frac{1}{2}}$, or the curve has two branches and $OP=\Omega-(\Omega^2-\Phi)^{\frac{1}{2}}$, $OP_1=\Omega+(\Omega^2-\Phi)^{\frac{1}{2}}$. Hence, as long as the roots are real and unequal, the curve consists of two ovals, one inside the other, as in Fig. 2. Since $n_1r_1+n_2r_2=n_0c$, $n_1OB+n_2(OB+c)=n_0c$, and hence $OB=(n_0-n_2)c/(n_1+n_2)$. In a similar way, OA, OC and OD may be found.

If a is the value of r_1 when $\theta=0$—for example, OC—and b is the corresponding value of r_2—for example, IC—and if b is *positive* when C is to the left of I, then $c=a+b$ and $n_1r_1+n_2r_2=n_0c=n_1a+n_2b$. Whence $n_0=(n_1a+n_2b)/(a+b)$. Then the general equation may be written as

$$(n_1^2-n_2^2)r_1^2-2r_1[n_1^2a+n_1n_2b-(a+b)n_2^2\cos\theta]+[(n_1^2-n_2^2)a^2+2n_2ab(n_1-n_2)]=0. \quad (3)$$

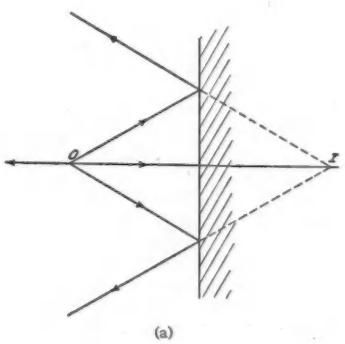
Obviously, with given values for a, b, n_1 and n_2 a complete set of values of r and θ can be obtained; so this equation represents the general solution of the problem. However, the equation is still so general that much of its contents is not obvious, hence the details that follow.

A. All cases of reflection require that $n_2=-n_1$. Therefore

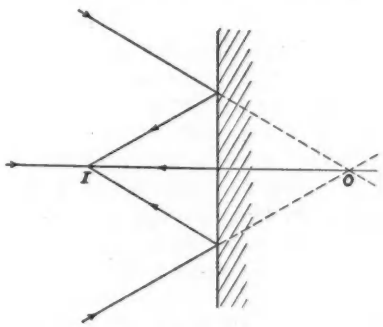
$$n_0=\frac{n_1a-n_1b}{a+b}=\left(\frac{a-b}{a+b}\right)n_1,$$

and Eq. (3) becomes $0\cdot r_1^2-2r_1[n_1^2a-n_1^2b-(a+b)n_1^2\cos\theta]+n_1^2\cdot4ab=0$. Since n_1^2 divides out, the result is independent of n, as it should be; and we have

$$r_1[(a+b)\cos\theta-(a-b)]=2ab. \quad (4)$$



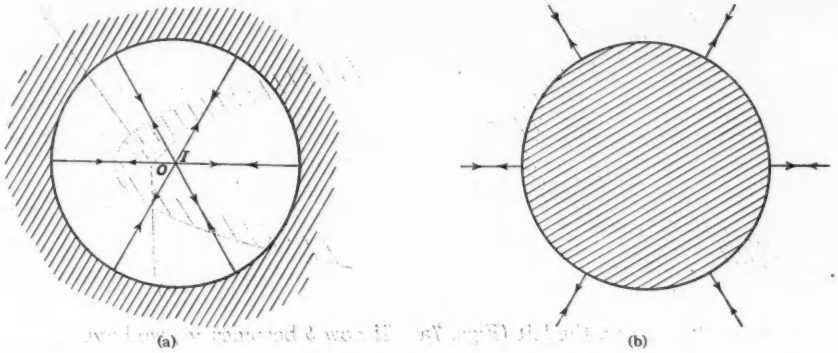
(a)



(b)

FIG. 3.

FIG. 4.



(a) (b)

Before simplifying this further let us consider first the condition that b is to equal $+a$; that is, the image-point is to be as far behind the surface as the object-point is in front of it. Equation (4) then becomes $r_1=a/\cos\theta$, the equation of a straight line. This gives, of course, the plane mirror (Figs. 3a and 3b). Now consider the condition that $b=-a$; that is, the image-point is to coincide with the object-point. The general equation becomes $r_1=a$, that of a circle, for which the familiar real object-point at center of curvature of a spherical mirror is one example (Figs. 4a and 4b).

FIG. 5.

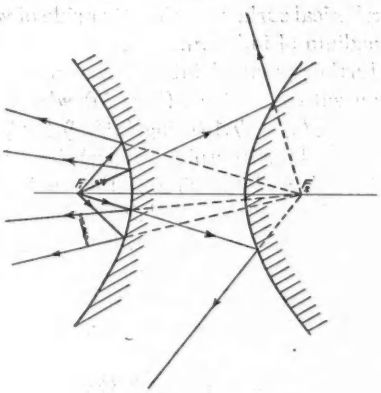
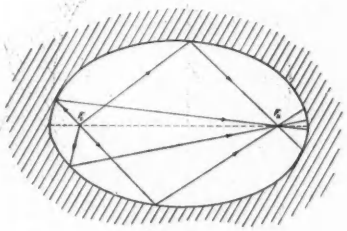


FIG. 6.



(a)

Now if we write Eq. (4) in the form

$$r_1=\frac{2ab/(a-b)}{\dfrac{a+b}{a-b}\cos\theta-1},$$

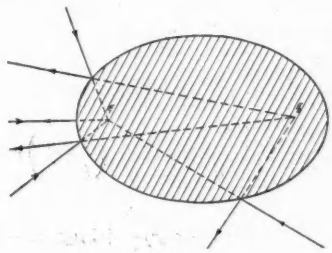
we have an equation in the form of the polar equation of a conic referred to one of its foci. The equation is that of a hyperbola if $e=(a+b)/(a-b)>1$, and this condition is readily met if a and b have like signs, that is, object-points and image-points on opposite sides of the surface (Fig. 5).

On the other hand, the equation is that of an ellipse if $e<1$ or if a and b have opposite signs, that is, if the object- and image-points are on the same side of the surface (Figs. 6a and 6b). If the usual equation of the ellipse is $(x^2/A^2)+(y^2/B^2)=1$, then $A=\frac{1}{2}(a-b)$.

For the parabola, it is best to go back to Eq. (4) and divide through by b, whence

$$r_1\left[\left(\frac{a}{b}+1\right)\cos\theta-\left(\frac{a}{b}-1\right)\right]=2a.$$

If now b becomes infinite, $r_1=2a/(\cos\theta+1)$, the



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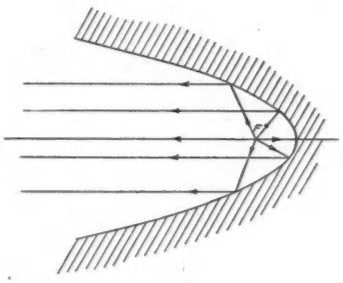
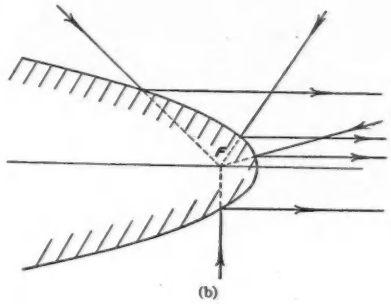


(a)

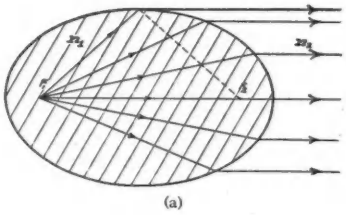


(b)

FIG. 7.

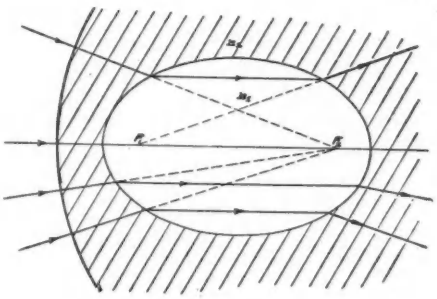
equation of a parabola open on the left (Figs. 7a and 7b).

If we remember that the light paths are reversible, we realize that these examples include all the possible cases for reflection.



(a)

FIG. 8.



(b)

B. Now consider the form of the equation when the surface is a refracting surface, that is, when n_1 and n_2 are unlike. In order to illustrate briefly the possibilities, we can best make use of special cases.

Division of Eq. (3) by b gives

$$(n_1^2-n_2^2)\frac{r_1^2}{b}-2r_1\left[\frac{n_1^2a}{b}+n_1n_2-\left(\frac{a}{b}+1\right)n_2^2\cos\theta\right]$$

$$+(n_1^2-n_2^2)\frac{a^2}{b}+2n_2a(n_1-n_2)=0.$$

If now b becomes ∞, we have

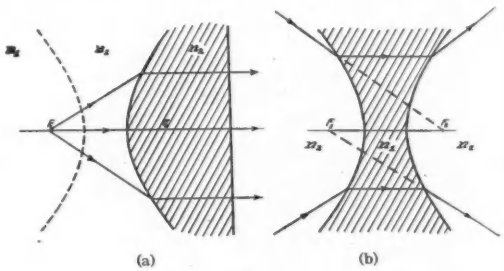
$$r_1=a\left(\frac{n_2}{n_1}-1\right)\Big/\left(\frac{n_2}{n_1}\cos\theta-1\right).$$

Again we have the equation of an ellipse or hyperbola, but this time the eccentricity e is equal to n_2/n_1 and the surface is ellipsoidal if $n_2<n_1$ (Figs. 8a and 8b), or hyperboloidal if $n_2>n_1$ (Figs. 9a and 9b). These surfaces were known to both Descartes and Huygens.

It is obvious that if we wish an object-point in the medium of larger index, $n_1>n_2$, it is always possible actually to use a point source in any medium so long as the source is made the center of a spherical surface on the other side of which is the medium of index n_1.

A further point of interest comes up in connection with the ellipse (Fig. 8a) where $n_2<n_1$. Since $e=n_2/n_1=C/A$ (using $(x^2/A^2)+(y^2/B^2)=1$ as the central equation of the ellipse), $B=(A^2-C^2)^{\frac{1}{2}}=A(1-e^2)^{\frac{1}{2}}$, and the sine of the angle of incidence of the ray from the left-hand focus to the end of minor axis is $C/A=e$; that is, this ray is incident at the critical angle.

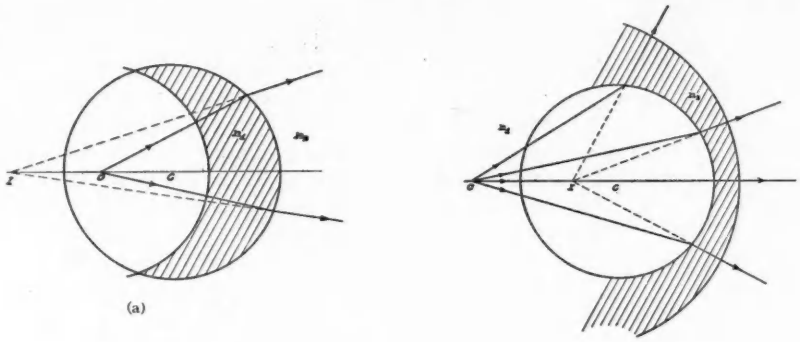
C. A case of unusual importance is shown by making $n_0=0$. This requires that $n_2=-n_1a/b$.



(a) (b)

FIG. 9.

FIG. 10.



(a) (b)

When the substitution is made in Eq. (3), we have

$$r_1^2-2r_1\cdot(a+b)a^2\cos\theta/(a^2-b^2) = -a^2(a+b)^2/(a^2-b^2).$$

Now changing to rectangular coordinates, we obtain

$$x^2+y^2-2x\cdot a^2(a+b)/(a^2-b^2) = -a^2(a+b)^2/(a^2-b^2),$$

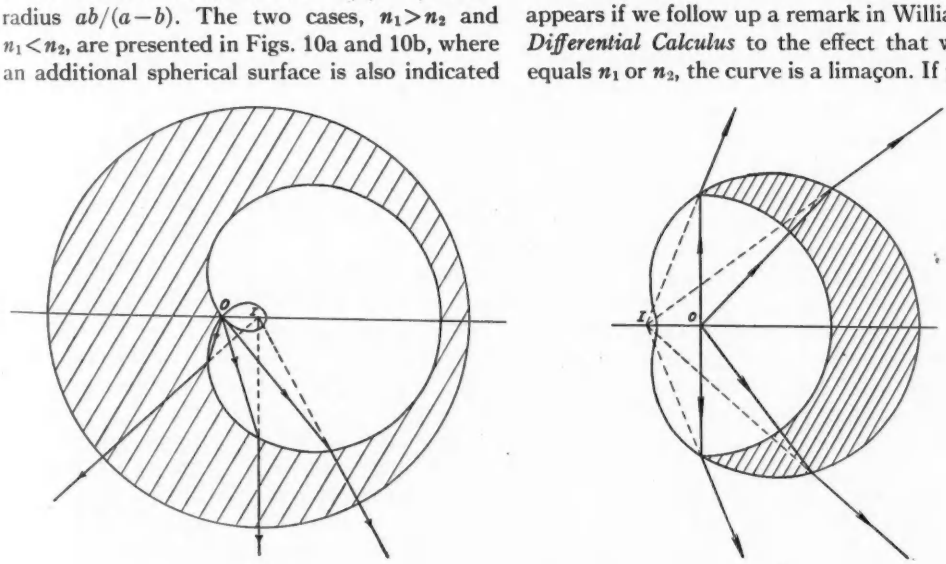
or

$$y^2+\left(x-\frac{a^2}{a-b}\right)^2=\left(\frac{ab}{a-b}\right)^2.$$

This is a circle with center at $x=a^2/(a-b)$ and of radius $ab/(a-b)$. The two cases, $n_1>n_2$ and $n_1<n_2$, are presented in Figs. 10a and 10b, where an additional spherical surface is also indicated to give a lenticular figure. The importance of these particular surfaces lies in the fact that not only do they satisfy the condition $\delta\Sigma nl=0$ but they also fulfill the "sine condition" and therefore have a prominent place in design of microscope objectives.

These spherical surfaces were certainly known to Huygens, and are identical with those resulting from "Young's construction," or from the "Weierstrass construction," the names indicating that at least the successors of these gentlemen were unaware of the extent to which the matter had previously been studied.

D. Another form of the general equation appears if we follow up a remark in Williamson's *Differential Calculus* to the effect that when n_0 equals n_1 or n_2, the curve is a limaçon. If positive



(a) (b)

FIG. 11.

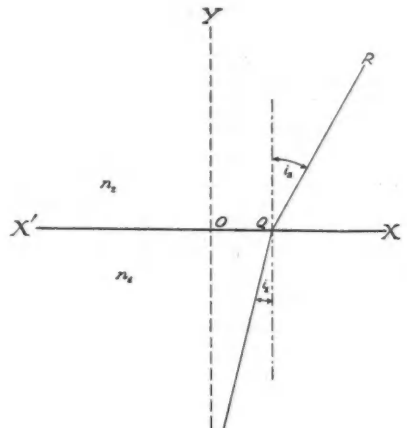


FIG. 12.

values are used, $n_1=n_2$, hence the consequences are of no interest optically. But if we take $n_0=-n_2$, then

$$r_1=\frac{a^2(1-\cos\theta)+2ab}{2b}=a\left[\frac{n_1}{n_1+n_2}+\frac{n_2\cos\theta}{n_1+n_2}\right].$$

The two cases, $n_1<n_2$ and $n_1>n_2$, are shown in Figs. 11a and 11b, with an added spherical surface.

It is entirely possible that there may be other special cases of refracting surfaces, but enough has been given to indicate how much attention has been devoted to the topic, and perhaps enough to show what are the chances that a major discovery will be made in this direction. Yet it is hardly fair to Huygens to stop at this point, since he shows how his method "conduit sans peine à trouver les lignes que requiert un costé du verre, lorsque l'autre est d'une figure donne; non seulement plane ou spherique, ou faites par quelqu'une des sections coniques, mais generalement quelconque." This seems to be as nearly a concluding remark as it is possible to make.

II. Huygens' Surfaces Following Refraction at a Plane Surface

With so many surfaces properly credited to Huygens, we may present as a typical surface, one which apparently he did not design, and if he had done so, would not have worked out as given below. In addition to this graphical solution of the problem of a suitable combination of surfaces for use in forming a point image of a point object after an initial refraction at a plane surface, we have included somewhat more of a reference to the caustic involved than would be necessary if the history of the caustic were generally familiar.

The particular problem refers to the imaging of an object-point at a depth d below the plane surface of a medium of refractive index n_1 when the medium above the surface has an index n_2. Let XX' (Fig. 12) be that surface, with the origin at O, and the object-point at P, $(y_1=-d)$. The equation for QR is

$$y_2=mx_2+b=\frac{(1-n_1^2/n_2^2\sin^2 i_1)^{\frac{1}{2}}}{n_1/n_2\sin i_1}\cdot x_2 - \frac{n_2 d}{n_1}\frac{(1-n_1^2/n_2^2\sin^2 i_1)^{\frac{1}{2}}}{(1-\sin^2 i_1)^{\frac{1}{2}}},$$

i_1 being the angle (incidence or refraction) in the first medium; or

$$f(i_1)=Gy_2-x_2+Hd=0, \tag{5}$$

where $G=(n_1/n_2)\sin i_1/(1-n_1^2/n_2^2\sin^2 i_1)^{\frac{1}{2}}$ and $H=\sin i_1/(1-\sin^2 i_1)^{\frac{1}{2}}$. Since

$$\partial(f)/\partial i_1=G'y_2+x_2+H'd, \tag{6}$$

the elimination of G and H from $f(i_1)=0$, and $\partial(f)/\partial i_1=0$ can readily be seen to give

$$x_2^{\frac{1}{3}}\left(\frac{n_1^2-n_2^2}{n_2^2}\right)^{\frac{1}{3}}+y_2^{\frac{1}{3}}\cdot\left(\frac{n_1}{n_2}\right)^{\frac{1}{3}}=d^{\frac{1}{3}} \tag{7}$$

as the equation of the envelope of all possible QR's. (See Fig. 13.) This envelope is the virtual "caustic by refraction"; it is recognizable as similar in form to the equation of the evolute of either an ellipse or a hyperbola, depending upon the relative values of n_1 and n_2.

The ellipse $(x^2/A^2)+(y^2/B^2)=1$ has for its evolute $(A\alpha)^{\frac{1}{3}}+(B\beta)^{\frac{1}{3}}=(A^2-B^2)^{\frac{1}{3}}$, α and β being the coordinates of points on the evolute. When $n_2=1$, Eq. (7) assumes exactly this form if multiplied by $d^{\frac{1}{3}}$, and written

$$[d(n_1^2-1)^{\frac{1}{2}}]^{\frac{1}{3}}\alpha^{\frac{1}{3}}+n_1^{\frac{1}{3}}d^{\frac{1}{3}}\beta^{\frac{1}{3}}=d^{4/3}. \tag{8}$$

Therefore, when the second medium is air, $n_2=1$, the caustic is the evolute of the ellipse

$$\frac{x^2}{[d(n_1^2-1)^{\frac{1}{2}}]^2}+\frac{y^2}{[n_1 d]^2}=1. \qquad (9)$$

For this ellipse, $A=d(n_1^2-1)^{\frac{1}{2}}$, and $B=n_1 d$; that is, its major axis lies in the Y axis (not in the X axis). In this ellipse, the distance from center O to the focus is $C=(B^2-A^2)^{\frac{1}{2}}=\pm d$, or the object-point is at one focus of the ellipse. The eccentricity e of the ellipse is $(B^2-A^2)^{\frac{1}{2}}/B=C/B=1/n_1$.

These facts are all presented by Southall[1] and by Born,[2] but they are certainly far from being common knowledge. The figure with its major axis in the X axis is an equal-phase or wave surface, but it is not an ellipse. The evolute is the locus of the centers of curvature of an infinite number of curves, all parallel, but not all on the same side of the center of curvature. In the case under discussion one of this entire group is an ellipse, and that ellipse is on the opposite side of the center of curvature from the wave surfaces in the medium ($n=1$).

To show how readily one may be misled, there is plotted in the first quadrant of Fig. 14 the *other* ellipse,

$$\frac{x^2}{[n_1 d]^2}+\frac{y^2}{[d(n_1^2-1)^{\frac{1}{2}}]^2}=1,$$

and that involute of the caustic which has the same intercepts on the axes. The points for this involute were computed by using a theorem

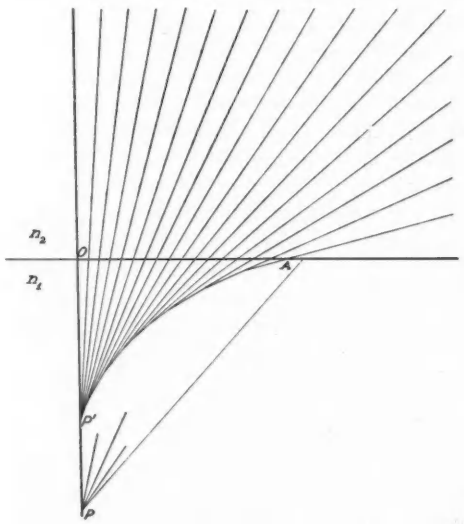


FIG. 13.

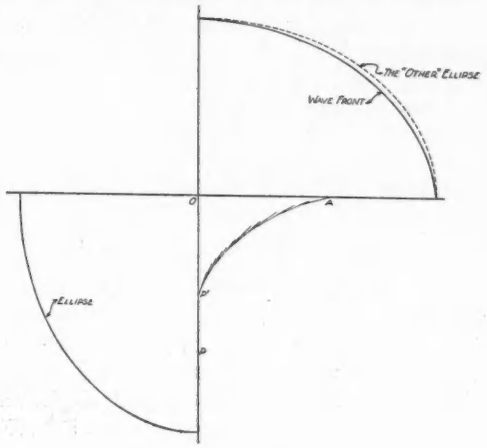


Fig. 14.

discovered, or rediscovered, by Dr. Seymour Rosin: "If $f(X, Y)$ has the same normals as $f(x, y)$, and the distance between the curves is c, the coordinates X and Y are given by

$$X=x\pm\left(\frac{c^2y'^2}{1+y'^2}\right)^{\frac{1}{2}},\quad Y=y\pm\left(\frac{c^2}{1+y'^2}\right)^{\frac{1}{2}},$$

where $y'=dy/dx$."

Since the data for the ellipse of Eq. (9) are supposedly complete, it follows that those for any other involute are as complete. However, for the present it will be assumed that it is possible to construct the wave surfaces with sufficient accuracy by unwrapping a thread held against straight pins set into a drafting board along the line of the caustic. Thus the minimum wave surface in the second medium, and as many others as are needed, can be easily generated.

The wave surface in the second medium being known, the next step is to find another surface, separating the high and low index mediums, which will refract all of the rays leaving the first medium so that they will all have the same real or virtual image-point. To do this we first introduce

[1] Southall, *Principles and methods of geometrical optics*, p. 59.
[2] Born, *Optik*, pp. 54ff.

above the minimum wave surface in medium 2 (for which we take $n_2=1$) a high index medium. Here, for simplicity, the refractive index of this medium has been taken as n_1, and a third surface is now to be formed between that medium and the air above.

The particular problem is to find the locus of all points S (Fig. 15) such that the ray RS will be refracted at S in a direction ST which is a continuation of OS. Obviously the wave surface after emerging into the final medium, $n=1$ (for simplicity only), will be a sphere with center at O. Furthermore, there is no need to have the path RS other than zero at the point C. Hence, since CRA is an equal phase surface, and DTB is to become one,

$$1\cdot CD=(n\cdot RS)+(1\cdot ST)=n\cdot AB. \quad (10)$$

Further, $OC+CD=OA+AB$. But OC and OA are known from the construction of the involute CRA. Therefore both CD and AB can be computed and the wave front DTB drawn.

To outline the method of locating S, denote AB by g, CD by h, RS by u and ST by v. Eq. (10) now becomes

$$h=nu+v=ng, \quad \text{or} \quad v=h-nu.$$

From this a table of values of v can be computed for all values of u from 0 to g. To locate S, first draw an involute of the caustic by unwinding a thread which has been adjusted to give $AS'=u$, and then draw a circle, center O, with radius $OD-v$; S is the point of intersection of these two curves.

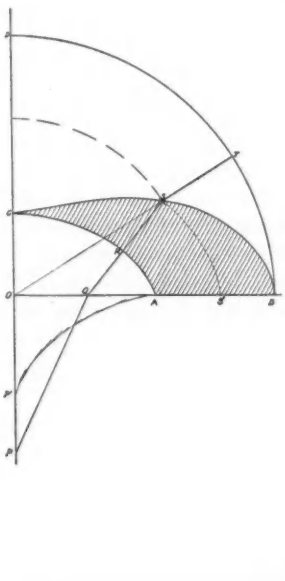


FIG. 15.

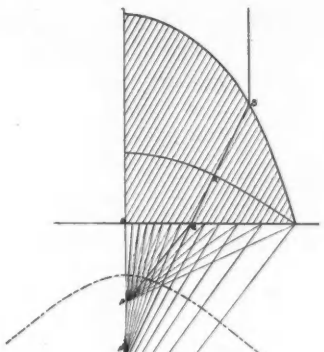


FIG. 16.

In this manner as many points of that third surface may be located as are desired. The final form of the surface is indicated in Fig. 15. For the diagrams it was assumed that $d=-10$, and $n_1=n_3=1.500$, but there is no necessity for the limitations assumed here. If anyone should attempt to make such a combination of surfaces, he would not be wise to make $RS=0$ at C. He could have the thickness anything he wished since CRA is a wave surface. The computation for any thickness other than zero is obvious.

There are, of course, three other problems quite closely related, the case in which $n_1<n_2$ (case II), where the same initial equations apply; and the two cases (III and IV) in which the object is virtual rather than real. For these last two, Eqs. (5) and (6) have the form $Hy_1-x_1+Gd=0$, and $H^3y_1+x_1+G^3d=0$, where G and H have the values previously indicated.

If $n_1<n_2$ (case II), Eq. (7) should be written

$$y_2^{\frac{1}{3}}(n_1/n_2)^{\frac{1}{3}}-[(n_2^2-n_1^2)/n_2^2]^{\frac{1}{3}}x_2^{\frac{1}{3}}=d^{\frac{1}{3}}. \quad (11)$$

For a real object in air at a distance of 10 units below a plane surface above which there is a medium of index 1.50, the equation of the caustic becomes

$$\beta^{\frac{1}{3}}\left(\frac{10}{1.5}\right)^{\frac{1}{3}}-\alpha^{\frac{1}{3}}\left(\frac{225-100}{2.25}\right)^{\frac{1}{3}}=10^{4/3}.$$

This is the evolute of the hyperbola, $45y^2-36x^2=2000$, so this time the equal phase surfaces are parallels of a hyperboloid. The object is at one focus of the hyperbola. By working forward from any wave surface in the second medium exactly as before, a second surface may be constructed which, with the initial plane surface, will constitute an aplanatic system (*aplanatic* being used in its early sense) for an image-point either at infinity, as in Fig. 16, or at a finite distance.

The lenses thus designed would be inconvenient to use, as well as of very limited service, but since the particular inquiry, in fact the entire review, was due to an old curiosity, the results may be of interest to others with a similar curiosity.

Nevertheless, the only real justification for this paper is again to review what has been done before. The part dealing with Cartesian surfaces is more nearly in form of a summary than is the second part. Yet Huygens himself might have done all that is given in the second part; he did, in fact, discover the proper surface for the problem of Fig. 16, although by a somewhat different procedure.[3] The ideas about the caustic and the various parallel involutes are due to Huygens. Hence, by making use of the properties of evolutes as presented in current mathematical textbooks, one is able to design surfaces, even the very same surfaces that gave Huygens the first knowledge of those curves we call *evolutes*.

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The Logic of Probability

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Probability as a Problem of the Philosophy of Science

If one proposes to survey in a limited space the logic of the probability concept, he must first look for a principle of selection; otherwise he could hardly do more than enumerate, in a tedious and useless show of erudition, the many problems and the several standpoints within this central and widely ramified field of the philosophy of science. Historical information not being of prime concern to the scientist or logician, a review of recent developments only would seem to be a justifiable restriction. Unfortunately, though, this restriction would not cut down the material sufficiently, because almost all the possible views ever held have representatives among prominent contemporary writers. This is a situation of which scientists easily grow weary and suspicious. What arouses suspicion is, of course, the all too familiar state of affairs in which age-old arguments are flung back and forth without any solution ever emerging—no matter how tentative a solution, but still a solution which could command a reasonably general agreement as the best answer available at the time. To deal with questions without answers is, as scientists see it today, the dubious privilege of speculative philosophy. It is not this type of philosophy to which contemporary scientists turn for help and guidance.

Considerations like this lead to another principle of selection. Let me illustrate by an analogy. The contemporary physicist, to be sure, is thoroughly unaffected by Kant's speculative arguments in favor of the synthetic *a priori* character of Euclidean geometry; this is true in spite of the fact that the Kantian view still lingers on among contemporary philosophers in slightly different trappings, especially among the German phenomenologists and the British intuitionists. Logicians and mathematicians are likewise indifferent to the claim of a synthetic *a priori* status for deductive logic which is being raised in the same quarters. But while scientists, mathe-

maticians, and logicians may be very wise to leave the metaphysicians to themselves, they still have profited from some of the weapons with which the anti-Kantian and anti-Aristotelian camp has been waging its lofty battles during the last two generations. The useful by-products of the epistemological discussion to which I here refer, are:

(1) The work in the foundations of mathematics culminating in Russell's deduction of arithmetic from a purely logical calculus;

(2) The work in the foundations of geometry with the emerging distinction between pure geometry as a calculus and applied geometry as a part of physics;

(3) The whole work done so far in logistics and general axiomatics;

(4) Finally, still useful to the scientist, though already on the fringe of epistemology proper, the so-called operational analysis of scientific concepts and procedure and the whole Neo-Humean approach to the meanings of terms such as *law* and *lawfulness or causality*.

This now is the analogy to our topic which I want to draw from these well-known developments. As the discussion of time, space, arithmetic, and causality has, under the influence of modern pragmatism and empiricism, veered away more and more from speculation and toward what modern scientists call the principles or foundations of their science, in the same way the philosophical discussion of probability is centering more and more around the foundations of the probability calculus. What is being studied is not any longer the metaphysical concept of chance, but the axiomatics of an existing mathematical calculus and the hypotheses underlying its application.[1]

In talking to scientists about probability, therefore, the best course for the philosopher is to discuss the logical and methodological problems arising in the foundations and the application of the probability calculus. If such a philosopher happens to be an empiricist, he might rejoice in the self-righteous conviction that in doing so he says everything about probability that can be said meaningfully according to his own bias. But still the fact remains that, from the viewpoint of some contemporary philosophers, the very choice of this avenue introduces a bias, or rather, several biases: a general, primary bias as to the relation of empirical to logico-mathematical knowledge, with respect to causality and induction; and, in consequence, a specific bias in favor of the frequency theory of probability[2] against the so-called classical and against modern logical and subjectivist theories. All I can do to avoid dogmatism and partiality and still say something in a restricted space, is to state explicitly that I am fully aware of this limitation. But the pattern I shall follow will be an exposition of the frequency approach, interspersed by all kinds of digressions referring to the underlying philosophical attitudes in general and to nonfrequency theories in particular.

Preliminary Statement of the Frequency Theory

Stated in a rough and preliminary manner, the frequency argument runs as follows: No matter what the exact status of the probability concept will ultimately turn out to be, no matter what the basis for the application of the calculus, whenever any probability statement is put to test, *what is being tested is always a prediction as to frequencies of an attribute within a mass phenomenon*. Statistical frequency is, therefore, the core and

[1] The term *foundations* or the equivalent term *principles* is here used in the same rather technical sense as in Hilbert's *Foundations of geometry* (ed. 1, 1899; ed. 7, 1930), the book that first made Hilbert's name famous outside of mathematics. The axiomatic method consists of studying the consequences, so-called theorems, which can be formally deduced from a given set of sentences, the so-called axioms. In such a formal treatment one can disregard the empirical meaning of certain primitive symbols (for example, "point," "straight line," "intersect," etc.) which occur in the axioms. The application or interpretation of the axiomatic system consists of co-ordinating, by so-called *co-ordinating definitions*, empirical constructs to these primitive symbols, and any such interpretation is clearly a tentative formulation of empirical laws. Sometimes several interpretations of one and the same axiomatic system are possible. In a certain sense the primitive symbols are, within the formal system, determined by the axioms only and only in relation to each other. For this reason an axiomatic system may also be referred to as a set of *implicit definitions*. However, because of the several logical and epistemological meanings of the term *definition* already in use, the latter expression has been recently discarded by some logicians.

[2] In the theory of probability the term *frequency* or *relative frequency* of an event A in a finite series of events $A, B, \cdots, K$, is a fraction; its numerator is the number n_A of events A (more precisely, events of the class A; for example, drawing a black ball), the denominator the sum $n_A+n_B+\cdots+n_K$. The case of an *infinite number of classes of events* or "attributes" adds none but mathematical difficulties. In the present paper the terms *frequency* and *attribute* are always used with these meanings. The questions arising in the case of an *infinite series* belong to the main body of the problem and will be discussed later.

mainstay of any empiricist analysis of the problem under discussion.

This is, to be sure, a rough and preliminary statement which leaves everything to be desired. But even on this preliminary level frequency theorists can marshal a very effective, quasi-historical argument. This is what they say: So far, there are three fields in which the concept of probability, and with it the calculus, has been put to actual scientific use. These fields are:

(1) *The games of chance*, with which Pascal, Fermat, the Bernouillis and even Laplace almost exclusively dealt. This application, though historically the first, is both practically and theoretically the least important.

(2) *Population problems*, covering a wide range of phenomena from life insurance to genetics and the theory of errors, practically very important and theoretically very instructive, because, so runs the argument, these applications clearly show the inadequacy of the classical combinatorial definition of probabilities as the well-known ratio of the favorable to the total number of all the "equally probable" possible cases. For, so it is asked, where are, in the case of a birth or death rate, the equally possible cases? What is meant in these cases by "equally probable"? It might be mentioned that a similar difficulty as to the very meaning—not the application of the classical combinatorial definition—arises in all cases where one of the two numbers becomes infinite and therefore in all cases of so-called geometric probability.

(3) The last, and theoretically the most important, application is the use which is made of *statistical methods in theoretical physics*.

These are, indeed, all the known applications, and all of them, so the frequency theorists argue, deal with *mass phenomena*, more specifically with mass phenomena thought of as subject to chance, where all that we can predict and measure, directly as in the games of chance, or indirectly by testing consequences as in theoretical physics, are relative frequencies. It goes without saying that it is one of the main tasks of each probability theory to give a more exact meaning to the colloquial reference just made to chance. But even before such an analysis is entered into, two points can easily be seen:

(1) If one restricts a precise and not merely colloquial use of the term *probable* and of its derivatives to such mass phenomena, one is free to make interpretations like the following one. The statement "The probability for a single number to come up on top in the usual game with one *unbiased* die is $\frac{1}{6}$" means "If the series of casts with such a die is *sufficiently prolonged*, the relative frequencies of these casts *converge* toward $\frac{1}{6}$."

(2) If the strict use of the term is so defined and thereby restricted to mass phenomena, it is not necessary to attribute any sharp and empirically testable meaning to a statement that ascribes a given probability to *any single event* in the mass series under consideration. And, vice versa, the probability statement must not be considered as a proposition asserting anything about any individual or, as one also says, elementary event. Such an interpretation would be only an erroneous use of the term not covered by its definition. As a matter of fact, so it is pointed out, one and the same elementary event—for example, the death of a man within a year's span—has different probabilities according to whether he is considered as a member of his age group, of the total population, of a professional group, and so forth. There is nothing paradoxical about this state of affairs if it is considered in the light of the frequency definition.

The Empiricist Frame of Reference

It is hardly necessary to call attention to the fact that almost all problems are still left open. What do we mean by a *series being sufficiently prolonged*, what by the *convergence of an empirically and not mathematically produced series?* What, finally, is an *unbiased die?* This, however, is what frequency theorists claim:

(1) The logical analysis of the problems just mentioned offers no difficulties other than those encountered in the analysis of the hypothetical assumptions of which all our theorizing, statistical as well as nonstatistical, consists. Two terminological remarks might be helpful at this point. First, *hypothetical* means here exactly the same as *inductive*. Second, within science a synonymous expression for *nonstatistical* is *deterministic;* this synonymity is rather confusing in view of the ethical and speculative connotations of the latter expression. Because of these connotations it is important to stress that so-called deterministic laws are also hypothetical or inductive.

(2) If probability is introduced as merely referring to limiting values of relative frequencies in so-called collectives, then the term *probable* disappears as a basic term of a precise empirical language. This, it must be emphasized, is the solution most consistent with the contemporary trend in formal logic and theory of knowledge. *A probability statement, then, is not a probable statement*, neither true nor false, but a statement, either true or false, about either a frequency in a finite series or the limiting values of such frequencies in an infinite series. Later on, the expression *series*, which is somewhat vague in this context, will be replaced by the technical term *collective*. The point to be made here concerns only the fundamental difference between definite and indefinite statements, that is, roughly speaking, statements about a finite number of particulars on the one hand, and statements about infinite classes, so-called generalizations, on the other. All significant probability statements are, as a matter of fact, generalizations of a rather complex structure, and, therefore, never completely testable. But this holds true for every generalized empirical statement, even the most elementary deterministic law of science or, for that matter, of common sense. For it is, in principle, impossible to check the infinite number of particular cases which each law claims to cover. What is frequently spoken of as the predictive value of science lies just in this ever-open horizon of future confirmation. But the inductive leap by which every law or generalization is reached can never be based on any rationalistic *a priori* grounds. It springs, as Hume first put it, from faith; or, as we put it today, it draws its justification from pragmatic grounds and from pragmatic grounds alone. In this sense, no inductive generalization is ever completely testable; it is merely probable. To say the same thing still differently, in epistemology the term *probable* serves no particular purpose; it has there exactly the same meaning as the terms *hypothetical* and *inductive*.

(3) At the present state of the discussion most experts are inclined to believe that, in statements such as "Hitler will probably lose this war" or "On the basis of the present evidence, the theory of light quanta is more probable than on the evidence available in 1920," the term *probable* is not quantifiable. As a matter of fact, such statements do not occur at all in a precise empirical language. If they are made and understood in common speech, they refer either to subjective beliefs or to some kind of fragmentary and insufficient knowledge of deterministic and statistical laws governing the case in question, or, not infrequently, to a mixture of both. In some cases it might be possible to elaborate some objective quantifiable meaning; more frequently, however, such an attempt will fail. In particular, no precise meaning has been given so far to estimates of the goodness of an inductive inference or of a theory.

There is no use in denying that such definitorial devices, with their melancholy crop of excluded objective meanings and the ensuing relegation of familiar usage to the limbo of lore and merely subjective meaning mark the way of progress in science as well as in logic and epistemology. Still, these exclusions are painful operations, and the arguments of the opposing traditionalists at least have the merit that they bare the more fundamental assumptions inspiring and directing such definitorial surgery. Let me restate the philosophical issue compresent in our case. If one disregards certain merely speculative arguments and identifies, for our purpose, testability with meaning, then the argument boils down to the question: Is the trichotomy *true-false-probable* necessary to characterize the outcome of a test, or is there a basic logical dichotomy only, *true-false* and in addition, of course, the incomplete testability or mere confirmability of any generalized statement.[3] If one prefers, in accordance with modern logic, the second alternative, then the loose use of the word *probable* is but a pragmatic reference to our expectations concerning the outcome of future tests. Let me finish this part of the discussion with what seems to me the strongest argument against the epistemological status of *probable* as an unreduced and irreducible term. If a scientist tests a generalized prediction, no matter whether deterministic or statistical, and obtains a positive result in, say, 90 percent of

[3] Terms like *testability* and *confirmability* are used here on the common sense level rather than with the precise technical meanings given to them in modern analytical philosophy. Though those finer distinctions are the epistemological basis upon which all arguments of this kind ultimately rest, their introduction would unnecessarily and forbiddingly encumber a presentation like this.

the cases considered, is it not an utter mistake and in open contradiction to actual practice to attribute to this law a probability of 90 percent and let it go with that? What one actually does in such a case is either to discard entirely the hypothetical generalization, or to formulate a new hypothesis about the role of variables so far not considered, the influence of which made itself felt in those 10 percent of the test cases, or, finally, to formulate a new hypothesis as to the interference of different laws. One then actually sets out to discover these improved or new hypotheses. So it seems, indeed, that there is no place and no need for the term *probable* in the analysis of induction and causality. And, if this is true, the frequency theorists are right in their contention that no relevant meaning is lost by the restriction of their analysis to the scientific and mathematical uses of probability notions.

A Subjectivistic Theory

This is the best place to mention the so-called subjectivistic theory of probability proposed by the late F. P. Ramsey. He is the same writer who contributed a brilliant and historically important remark to logic, but who, in his treatment of probability, for once fell victim to the intuitionistic influences prevailing in some circles of his environment, the old schools in England. If called upon to state in one sentence what this intuitionistic doctrine consists of, I should characterize it as the belief that one can find out something about facts by finding out what people say about them. Let me illustrate what I mean by this misplaced subjectivistic and psychologistic reference by briefly describing Ramsey's ideas on probability. We know, so one might imagine him to argue, what a person means by truth and falsehood. Let us find out then in the psychological laboratory, so to speak, what we mean by probability. Accordingly, he proposes to submit to his subjects a carefully selected set of questions concerning their estimates about the probable occurrence of future events, among them those whose probability we want to determine. No axioms as to the outcome of these experiments, no clever devices pertaining to the elimination of what Ramsey calls emotional preferences can conceal the two fundamental weaknesses of his argument. First, it is absurd to make any *axiomatic* assumptions as to how people are going to behave in such experimental situations. Second, no matter how they behave, the whole thing is, if anything at all, a study in social psychology rather than a logical and methodological analysis. The whole business amounts to this: in order to determine the probabilities of a future event, one watches the bets that people lay on this event.

Let me state another argument which has been put forth to show the futility of such introspectionistic or pseudo-behavioristic approaches. If the guesses of the bettors are to be of any significance at all, they must be what one usually calls rational beliefs. Upon what else, then, could these beliefs be based but upon past experiences of the bettors? And what does such past experience consist of, if it is not either some knowledge of frequencies heretofore observed or else some knowledge concerning the deterministic laws in question? The latter kind of knowledge, as we shall presently see, is knowledge of so-called *a priori* probabilities. Thus the whole intuitionistic argument is a psychologistic roundabout either to the classical *a priori* or to a frequency theory of probability.

The Classical Theory

The best way to prepare for the next step—an analysis of the so-called classical or Laplacean conceptions—is to sum up some further aspects of the Neo-Humean analysis which serves us as a general frame of reference.

(1) A statistical law is not any worse than, or logically different from, a so-called deterministic law. The whole distinction *statistical-deterministic* is relative and can be applied only with respect to two corresponding levels: one, let us call it the lower one, of individual or elementary occurrences and one of mass phenomena constituted of manifolds of such elementary phenomena. With reference to two levels of this type a prediction or law about the lower level is called *deterministic*, while a prediction about the compound level is called *statistical* with reference to the lower level. What, in any given case, is to be considered as the elementary level depends upon the nature of the case, the type of analysis attempted and the means available. There is no absolutely and ontologically determined level of atomic facts any

more than there are atomic sentences in any absolute not merely linguistic sense.[4] To say the same thing in a suggestive paradox: A statistical law is a deterministic law about the collective object. Even to say as much as that a statistical law is preferable to a deterministic law is misleading, if one does not add immediately that this evaluation refers only to a possible difference, present in some but by no means in all cases, concerning the reliability of the inductive inference which is involved in either type of generalization.

(2) There is no *a priori* principle of causality, principle of induction, principle of the uniformity of nature, or however one might call a speculative guaranty, that one must discover laws in any realm of experience. There is only a pragmatic expectation that one will actually find them, and a corresponding rule of procedure based upon past successes. There are, therefore, *a fortiori* none but merely speculative reasons to assume that one must find deterministic laws on any level of analysis.

If, however, we are in actual possession of both types of laws for two corresponding levels, then and only then does there arise the question of their interrelationship, or more vaguely but more suggestively speaking, the question as to what light they throw upon each other. This is no philosophical problem, but a problem within inductive science. The case I am here referring to is by no means an entirely theoretical one; it has actually arisen in the games of chance with unbiased dice, where we do know both the frequencies from a long series of experiments, and the laws of mechanics which, at least in principle, whatever that might mean, allow for a prediction of the individual cast, provided the mechanical properties of the die and the throwing procedure are sufficiently specified. The consideration of this situation paves the way to an understanding of the classical Laplacean theory, of its key concept of *a priori probability*, and to the clarification of the empirical core of another speculative principle, the *principle of indifference* or, as one might also call it, a causality principle of insufficient reason.

Let me begin with the assertion that the term *a priori probability* itself is an unfortunate misnomer, to be understood only historically as a terminological aftereffect of the rationalistic-realistic background of Newtonian and Laplacean mechanics. Laplace's argument, somewhat readjusted, runs as follows: On the basis of our knowledge of mechanics and in view of the limitations of our knowledge about the actual conditions of each throw, we can only say that with an *unbiased* die and with an *unbiased* procedure—*unbiased is here a term of mechanics* (center of gravity in the geometric center and so forth)!—all possible outcomes of the casts with one die are equally probable; that casts with two dice are, again in the sense of mechanics, at least approximately independent of each other, and similar statements like that. What does this mean?

If these probabilities are mere beliefs, no matter how rational or irrational, then they are entirely irrelevant for an investigator interested in the outcome of chance games and not in the attitudes of the players. Hence they must be considered, and practically are considered also within the classical theory, as predictions about frequencies to be observed. Thus interpreted, the question as to the existence of *a priori* probabilities amounts to this: Can these frequencies actually be deduced from the known laws of mechanics, in the strict sense of a *logico-mathematical deduction within a scientific theory?* The belief in the possibility of such a deduction is, as far as I can see, the empirical content of the thesis that the probability calculus and its application can be based upon so-called *a priori* probabilities. This shows how misleading the use of the philosophical term *a priori* is in this context, for there is nothing *a priori* about *a priori* probabilities. Rather, the question is whether

[4] This is one of the basic tenets of any empiricist theory of knowledge. The basic terms from which our theoretical reconstructions start are atomic only in the sense that they are, roughly and illustratively speaking, the primitive terms of an axiomatic system (cf. footnote 1). The empirical referents of these terms, however, if such referents exist at all, are as a rule very complex empirical constructs. What is atomic in this sense today might, with a change in theory, be compounded tomorrow, and vice versa. Again, any linguistic structure starts from certain symbols and syntactic forms not amenable to any further analysis within *this* language. But this *logical* atomicity is clearly relative to the language chosen in the same way in which *physical* atomicity is relative to the theory under consideration. It should also be mentioned in passing that the lack of any objective meaning whatsoever of the term *atomic* is the main predicament of Wittgenstein's sketch of a so-called logical theory of probability.

certain deductive connections can be established between different strata of empirical science which itself is entirely *a posteriori* if an epistemological term has to be employed by all means.

It is well known and pretty obvious that no such deduction has been offered so far, and that none is likely ever to be achieved. It is true, though, that we *expect* statistical experimentation to yield equal frequencies in the corresponding mass phenomena whenever the deterministic laws of the elementary level are known and do not indicate any greater probability, *in the vague use of this word*, for any side of the die to come out on top. However, this correspondence between what one might call mechanical indifference or symmetry and equal frequency is no deductive connection within science, and therefore cannot be based upon any theoretical grounds within science. If speculative philosophy tries to buttress this expectation by an *a priori principle of indifference*, a kind of negative principle of causality, this again is of no concern to scientists, logicians or empiricist philosophers. On the other hand, however, any derision of such an *a priori* principle of insufficient reason as a glorification of ignorance shows rather a lack of understanding. As a pragmatic expectation, this principle is not any worse or better than a principle of causality or sufficient reason, though extreme cautiousness is advisable even in its heuristic application. As shown by the analysis of some historically well-known problems, the "symmetry" might be a function of the co-ordinates chosen rather than an indication of anything else. The upshot of these considerations is that for the scientific use of probability notions we are again thrown back upon frequency interpretations, to which I shall now turn without further digression. If I have so far spent much of my time pointing out difficulties of the other approaches, I shall henceforth have to call attention to the many difficulties, some of them rather subtle, by which, unfortunately, the frequency theory is also beset.

Problems of the Frequency Theory

Let us begin with a modicum of historical notes. The earliest advocates of a frequency interpretation were, in the last century, the Austrian Bolzano, the English logician Venn, and in this country Charles S. Peirce. But it is only in our time that the theory has found a technically competent and detailed exposition in the writings of von Mises during the last twenty years. It is fair to say, though, that von Mises' work has been considerably improved, especially in its more subtle logical and mathematical aspects by a group of younger students such as Doerge, Kahmke, Reichenbach, Tornier, and, mainly, Copeland and Wald. One might even say that only by their elaborate researches has von Mises' ingenious structure been prevented from crumbling. For the problem is, after all, not a restatement of common sense, but a logical foundation in the strict sense of the term.

The very crux of the problem is the definition of the *collective*. Consider a series of drafts from an urn containing white and black balls only, and make the usual assumption, that the drawn individual is put back after each draft. Let us agree, further, to denote each white or black ball drawn by the numbers 1 and 0, respectively. What our record then shows is *an initial segment of an infinite series exhibiting a chance distribution of 0 and 1*. At this point of the argument the distinction between a calculus and its application becomes all important. In this respect the situation is analogous to the well-known one in geometry, though, as we shall see, much more complex. An infinite series, it must be remembered, is a purely mathematical object, and if the mathematician is asked to define a class of infinite series by postulating those properties that express what is vaguely meant by a chance distribution, he is given a purely mathematical, or as the logician likes to express it, a purely analytical task. Until this analytical problem has been solved, the second question cannot even be asked. This second question, the problem of application, is: What are the criteria according to which we inductively decide to consider a given experimental rule—say, dice throwing—as producing initial segments of a collective?

The task devolving to the mathematician then is (1) to set up in an axiomatic way the criteria of that class of infinite series which we call collectives, and (2) to show that this class is not empty or, to put it differently, to show that whatever he has thus defined, *exists as a mathematical object*. But it is to be stressed once more:

Mathematical existence itself has nothing to do with the empirical application of an existing mathematical object or calculus. Thus we are faced with another logical problem, that of mathematical existence, which occupied much of the interest of the mathematical philosophers during the twenties. The discussion I am here referring to is that between the finitists or intuitionists (this is another strictly technical meaning of the term *intuitionism*) led by Brouwer, and the logicists and formalists led by Russell and Hilbert. To the formalist, mathematical existence means freedom from contradiction or, as the contemporary formulation of this old Leibnizian idea reads, the consistency of a formal system, while the intuitionists require actual finite construction within the system.[5] Accordingly it is only the formalist who can speak about convergence and limits of an infinite series which is not actually given by a finite formula. The series

$$\tfrac{1}{2}, \tfrac{2}{3}, \tfrac{3}{4}, \tfrac{4}{5}, \tfrac{5}{6} \cdots,$$

for example, is generated by the simple formula

$$x_n = n/(n+1)$$

and it is said to converge toward the limit 1; or in symbols, $\lim_{n\to\infty} x_n = 1$. Take, on the other hand, a series about which we only know without actually controlling its terms that the further we progress in it, the less its terms differ from a certain given number x. In logistic symbols

$$\lim_{n\to\infty} x_n = x$$

if and only if

$$(\epsilon)(\exists N)(n)(n > N) \supset (|x_n - x| < \epsilon).$$

The formalist still says that this series converges towards x as its limit, while the finitists have doubted the meaningfulness of such a statement.

It is quite obvious that the existence of collectives, if it can be demonstrated at all, could never be demonstrated but in the formalistic sense of mathematical existence. For how could a *chance* distribution ever be caught by a finite mathematical *formula?* At present, though, after the finitist criticism has yielded its full contribution, this is no longer considered as a serious limitation. So one can safely proceed to formulate the first defining property of a collective. For simplicity's sake we restrict ourselves to a distribution of a finite number of attributes, for example, 1 and 0, representing white and black drafts as before. Then the postulate reads: *the limits of the relative frequencies of each attribute exist.* These limits are what we call the probabilities of the attributes in the collective. This first postulate does not offer any difficulty. As a matter of fact, it was formulated by Venn, though with much less caution and sophistication than mathematical philosophers nowadays feel compelled to exhibit. But this first postulate is quite obviously only a necessary and not a sufficient criterion for a collective; consider, for example, the decimal development of a rational fraction, say 1/999:

001 001 001 ···.

The limits of the relative frequencies exist and are $\frac{1}{3}$ and $\frac{2}{3}$, respectively, but still we do not consider this series as a chance distribution, the reason being that it is possible to affect the limits by what von Mises calls a *place selection.* A place selection is any sub-series of the given series selected according to a rule that does not contain any reference to the result of the draft; for example, given any distribution of 0's and 1's, the selection of every second, of every third or of every draft the position of which is indicated by a prime number is a place selection. With this in mind one might try to postulate the second property which every collective must possess: namely, the limits of the relative frequencies in a sub-series created by any place selection must exist and have the same limiting values as the relative frequencies of the respective attributes in the original series from which the place selection has been made.

This is what von Mises calls the *axiom of randomness*, or also, with a rather suggestive expression, the *principle of the impossibility of a gambling rule*, for that is what this principle, as one easily sees, amounts to. Now I ask you to

[5] All formal systems are so arranged that if they contain a single sentence, together with its negation, every sentence can be derived. Such a system would be empty. The insistence on the principle of noncontradiction or on consistency (in a finer analysis these two terms are not quite identical) is, therefore, a formal requirement and not a vestige of a nonformal ontological logic. On the other hand, it is also easy to see that the simultaneous assertion of both a statement and its negation would obviate the referential function and thus any possible application of the language.

remember again that we are not yet concerned with applications, and besides, that the reference to experimental results of statistical phenomena would be, in principle, out of place as long as we discuss statements about *infinite* series and about *all* or *any* place selection among them. What one has to solve is the problem of mathematical existence; that is, one has to decide whether infinite series exist which have both postulated properties, namely, existence of the limiting frequencies and randomness. Here the trouble starts. Mathematically, and we are still in mathematics, the randomness axiom cannot even be formulated, or rather, if it is formulated, we are sure that there is no series for which it holds. For, among *all* the place selections, there are certainly also those that contain only 1's, only 0's, and so forth.

Everybody will admit at this point that the outlook does not seem to be particularly bright for the frequency theory either. As a matter of fact, it is not believed today that the unrestricted axiom of randomness as originally formulated by von Mises can be incorporated into any deductive structure. But by the combined efforts of the previously mentioned group of workers, mainly Copeland and Wald, the following result finally has been secured:

Given an arbitrary distribution, that is, a set of probability fractions summing up to 1, and an arbitrary enumerable set of place selections, it is possible to define a collective (even a non-enumerable set of collectives) in which the relative frequencies of the particular attributes tend to the limits prescribed by the given distribution, and this is not affected by any of the place selections of the given set.[6] To repeat in nontechnical language: For any enumerable set of gambling rules there is a non-enumerable set of series that show the required stability of the limiting frequencies (first axiom) and against which none of these gambling rules will prevail (second axiom).

It is obvious that this restricted randomness is sufficient to warrant any application of the concept of a collective, for one never tests more than a finite, let alone an enumerable, set of gambling rules, and one tests, moreover, any single one of them but incompletely, that is, in initial segments. The mathematical existence of the main requirement of any frequency theory, the noncontradictory character of the restricted collective, can, therefore, be considered as established by the work of Copeland and Wald. Thus the path is free for the earlier developments of von Mises: the analytical construction of the calculus of probabilities by deriving infinite series from infinite series by means of certain rules of procedure and then (1) analytically proving that these derived series are again collectives, provided only that the original ones are, and (2) determining the probabilities (limiting frequencies) within these derived collectives as functions of the probabilities in the original ones. The establishment of these functional connections between probabilities is obviously a purely mathematical calculus. In this way the whole classical calculus of probability can be reconstructed. It is helpful to reformulate this result in a slightly different way. The class of collectives and the basic operations between them can be considered as a mathematical model of the usual calculus of probabilities axiomatized in the classical fashion, in the same way in which, for instance, analytical geometry can be considered as a mathematical model or interpretation of the geometrical calculus whose basic propositions are the axioms of Euclid, or of whatever non-Euclidean calculus one attempts to interpret.

This way of looking at our problem also brings out very well the point in which the situation differs radically from that in geometry. The *direct* empirical application of a geometric calculus by interpreting it in terms of physical objects and their relationships without the interposition of a further mediating mathematical model or interpretation is possible.[7] *With an axiomatization of the probability calculus in the classical style, this cannot be done.* The basic terms of such an axiomatization are certain fractions called *probabilities* and relations such as *inde-*

[6] *Enumerable* and *non-enumerable* are terms of the theory of infinite numbers. It is sufficient to say that the infinite number of all fractions is still enumerable, while the infinite number of all numbers, fractions and irrational numbers is not enumerable.

[7] Technically, such an interpretation of one calculus "into another" is now called a *translation*. Vaguely, it can be characterized as the discovery of a formal or structural identity of one system with another or with a part of another. All mathematical isomorphisms are such translations.

pendent, corresponding to multiplication, *mutual exclusion*, corresponding to addition, and so on; and one cannot empirically interpret these axioms for the very simple reason that one does not know what they mean except in terms of finite relative frequencies and of operations performed on finite statistical collectives. Hence, the intercalation of the collective is indispensable, and there does not seem a way to avoid all the logical and mathematical difficulties which are inherent in this rather complex situation.

Problems of Application

Turning to the question of application, although it must be said that the empirical or inductive aspect of our problem also shows very embarrassing peculiarities, these at least are formally less involved. As pointed out before, the main question is how to decide whether a certain experimental rule actually produces a collective, so that our application of the calculus will lead to correct predictions. Shall we make 100 throws, or 1000 or 10,000? And, after we have chosen such a number, what deviation from the limit has taken place? Any kind of answer to this second question obviously would imply a *uniformity of convergence* in all the collectives. Aside from the fact that such a uniformity has never actually been observed, its assumption would lead to contradictions with certain purely analytical consequences which can be drawn within the calculus. These consequences are better known under the name of *Poisson's law of large numbers*. As a matter of fact, Poisson's formula has been one of the big stumbling stones during the history of our problem. Suffice it to say that these difficulties have been definitely eliminated. The result of this analysis is: Poisson's law does not contain any empirical prediction about the convergence, uniform or not uniform, of empirical series, but is a purely mathematical theorem within the calculus, deriving probabilities from other probabilities as all the theorems of the calculus do. This cannot be repeated often enough, the more because there are still certain aftereffects of the earlier confusion with regard to this point to be found in very recent writings.

But such criticism still does not solve the problem of application. If there is no uniformity of convergence, what, then, are the criteria for an application of the calculus? The answer is disappointing, but at least short: *There are no criteria except those that are in turn based upon the assumption of the applicability of the calculus*. This applies also to all modern sampling technics which, in a philosophically loose and general way of speaking, are all based upon Poisson's decisive, but merely mathematical, idea. To indulge in a figurative way of speaking: If tomorrow the world should enter into a statistical eclipse, in which only the improbable cases occur, the calculus of probabilities would no longer be applicable. But neither would Euclidean geometry be applicable if tomorrow our world should become what has been called a rubber world in well-known thought experiments. Considerations of this kind are the stock-in-trade of the contemporary empiricist theory of knowledge.

A certain closure of thought shows itself at this point. Starting from epistemology, the argument proceeded to a sketch of the formal analysis and now turns back to epistemology again. Let me then, in conclusion, at least mention those writers whose work could not even be touched upon in this brief exposition. Their views are usually referred to as *logical theories* of probability. Actually, there exists only one explicit and detailed presentation of such a theory, the *Treatise on probability* (1921) by J. M. Keynes, the famous economist. Since then, the opinion that this approach is irreconcilable with the most basic ideas of both modern logic and the empiricist theory of knowledge has become, to say the least, very widespread among the experts. Finally, the omission of the work of Reichenbach requires an explanation. Reichenbach's constructions are not so much a theory of probability as a probability theory of logic and empirical knowledge. This ambitious attempt naturally lies on the outer fringe of our topic. But its very possibility indicates how central a position the concept of probability occupies within contemporary analytical philosophy.[8]

[8] For further nontechnical information and references to original sources, see: E. Nagel, "Principles of the theory of probability," *International encylopedia of unified science* (Univ. of Chicago Press, 1939), vol. 1, No. 6; R. von Mises, *Probability, statistics and truth* (Macmillan, 1939). Nontechnical information concerning the philosophical background will be found in: R. Carnap, "Foundations of logic and mathematics," *International encyclopedia of unified science*, vol. 1, No. 3; R. Carnap, "Testability and meaning," Phil. of Sci. **3** (1936); **4** (1937).

Dayton Clarence Miller: Physics Across Fifty Years

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ON April 6, 1940, a group from the Department of Physics of Case School of Applied Science drove through Strongsville, Ohio, with DAYTON C. MILLER on their way to the first meeting of the newly organized Ohio Section of the American Physical Society. They stopped in Strongsville, where PROFESSOR MILLER was born on March 13, 1866, and he related many of his early experiences.

As a small boy, DAYTON spent much time with his GRANDFATHER POMEROY, whose large brick house and store marked him as a leading citizen of the community; indeed, he was one of the original trustees of Oberlin College and a founder and director of one of the most important banks in Cleveland. The opportunities to participate in productive enterprise were many on POMEROY'S 2000-acre farm, and Dayton helped make maple sugar, shear sheep, bale wool, smoke hams, and perform other farm duties. The store, too, was a great education for the boy. GRANDFATHER POMEROY went to New York twice each year to buy the stock for the store and some member of the family always accompanied him. On their return, the younger members of the family eagerly listened to the stories of the journey to the great metropolis. DAYTON MILLER'S interest in travel and his conviction about the value of visiting distant places to learn things firsthand developed at this early age.

When DAYTON was eight years old the MILLER family moved to Berea, Ohio. The landmarks in Berea are still much as they were in his boyhood, and he took great delight in showing them to his friends who accompanied him and MRS. MILLER to the annual Bach Festival each June. He would point out the home on the corner, the hedge he clipped, the barn, the vegetable garden where he raised produce for the family table and earned the money for his bicycles and his first silver flute; the German Methodist Sunday School which he attended and where he mastered the German language, another church where an indulgent priest allowed him to play the pipe organ and examine it with the aid of a screwdriver. He would point out the corner where his father's hardware store had stood, and the bank where he worked with his uncles during summers and one year after college.

DAYTON MILLER'S early interest in music developed naturally, as his mother was church organist and his father sang in the choir. One of his earliest toys was the piccolo played by his father in a fife and drum corps during the Civil War. In time he outgrew this instrument and decided that he needed a silver flute. With characteristic paternal wisdom, DAYTON'S father told him he would have to earn the money for the flute, so the boy grew and sold vegetables and saved money until he had about $90 of the $145 necessary to buy the flute. When this determination was displayed, his father gave him the money needed to make up the difference. In his study of harmony he found that by removing the front from the upright piano and watching the hammers as various sequences of chords were sounded, he could get a more realistic idea of the meaning of concord and discord than by looking at the black and white keys; this is characteristic of his attitude in approaching all problems.

His interest in making things for himself in the tin shop of his father's hardware store led to a keen interest in telescopes and astronomy. He made three telescopes, and the last, a fine 5-in. refractor, is now at Case School of Applied Science. His early researches in astronomy are recorded in a series of observational notebooks. The sketches of sunspots and comets are works of art.

When DAYTON was nineteen, his father took him on a business trip to Philadelphia and they stopped in Pittsburgh to call upon JOHN A. BRASHEAR and see his optical shop and telescopes. This was one of the great events in his early scientific career. He said recently that "John A. Brashear was my scientific father," and the fact that he went into astronomy instead of continuing in the business opportunities open to him was largely due to the early inspiration received from the Pittsburgh master.

DAYTON was graduated from Baldwin College in Berea in 1886. At the commencement program he presented a lecture on the sun and gave a solo on his silver flute. This combination of activities typifies the entire career of DAYTON C. MILLER. The blending of art and science in all of his enterprises was complete and inseparable. One of the last flutes added to his collection, in February, 1941, was a duplicate of the silver flute which he played at these commencement exercises in Berea.

After graduation from college he was undecided whether to go on in business, with all the attractive opportunities of the Middle West of that day, or to study the organ at Oberlin, or to go to Princeton and study astronomy. His father's advice was to go into business. "I can help you there but not in astronomy," he said. But after a year in his uncles' bank in Berea, he decided for Princeton and astronomy.

He went to Princeton without previous laboratory experience. His work there was directed by PROFESSOR CHARLES A. YOUNG who gave him a sextant and a chronograph and told him to measure time; also, an interferometer and told him to measure the wave-length of sodium light. He was left entirely to his own devices in this and most of the other work in which he learned the technics of physics and observational astronomy. His doctor's dissertation consisted of the calculation of the orbit and elements of the Comet 1889 *V* based upon his own observational data. He elected all the courses offered in mathematics and physics and also PRESIDENT JAMES MCCOSH'S course in philosophy which was given to a small group in the president's study. Here were planted the seeds of a realistic philosophy that involved a conviction of the essential unity of aesthetic values and scientific truth as components of the fundamental order of the universe. This early conviction he never lost. While at Princeton he made a trip to New York to hear his first Wagnerian opera, *Die Walküre*. His diary records wonder and delight, "greater than anything I had dreamed possible."

The conscientious industry of DAYTON MILLER as he worked with PROFESSOR YOUNG resulted in his receiving the degree of doctor of science at the end of his second year, the only one of his group of twelve to finish so quickly. His diary for the day in 1890 when he received his degree records the Princeton college yell, with the letters "D.Sc." substituted for the usual closing, "Rah, Rah, Re."

PROFESSOR YOUNG secured DAYTON'S appointment to the newly founded Thaw Fellowship in Astronomy, the work to consist of the study of stellar spectra, using a new prism spectrograph then under construction by BRASHEAR in Pittsburgh. That summer DAYTON went back to Berea in triumph. If a certain cast of Jena glass had been perfect, there seems little doubt that his career would have developed at Princeton in astronomy; but BRASHEAR found the glass for the prisms defective and announced that a year would be required to obtain a new batch and have the prisms properly ground. This news was broken to DAYTON in a letter from PROFESSOR YOUNG, suggesting that it would be desirable to wait a year before accepting the Thaw Fellowship.

That same day he made a journey to Cleveland to visit the recently founded Case School of Applied Science. A fire had devastated the main building and destroyed all the new apparatus purchased by Michelson for the work in science. On the day of DAYTON'S visit the repairs were by no means completed, and his first entrance into the main building was over a plank used by workmen for carrying in materials. The young man walked into PRESIDENT STALEY'S office and found the president in conference with DR. CHARLES S. HOWE, professor of mathematics and later the second president of Case School. Introducing himself and explaining that he would like a chance to teach at Case for one year, he gave the details of his work with PROFESSOR YOUNG, and told of the Thaw Fellowship and the Brashear prisms. Both men were greatly interested in the young man from Berea, DOCTOR HOWE especially, since he taught the astronomy at Case; the idea of having one of PROFESSOR YOUNG'S disciples for a year seemed very attractive. However, it was already midsummer and the only possible opening was an instructorship to teach descriptive geometry as PRESIDENT STALEY'S assistant, and a few classes in mathematics under DOCTOR HOWE. Young MILLER accepted this opportunity, and proved such an excellent teacher that he never returned to

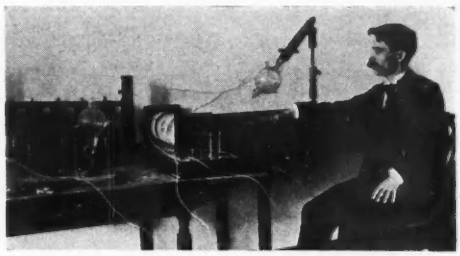
DAYTON C. MILLER IN 1922 WITH THE GOLD FLUTE WHICH HE DESIGNED AND CONSTRUCTED.

Princeton. In his second year at Case he also taught calculus, and in the third year, some classes in physics.

In 1892 HARRY FIELDING REID, professor of physics at Case, was called to the Johns Hopkins University as professor of geophysics. At the suggestion of DOCTOR HOWE, PRESIDENT STALEY gave the work in physics to DAYTON MILLER for a year or two "while they were looking." The teaching of physics was very much to his liking. It gave him a chance to build apparatus for the demonstration lectures and the laboratory courses—duties which he preferred to the routine of the mathematics classroom. At the end of that year (1893) he was made assistant professor in charge of the work in physics.

In 1893 PROFESSOR MILLER and EDITH EASTON of Princeton, New Jersey, were married. The same year they made an extended visit to the Chicago Columbian Exposition and while there purchased for the Department of Physics a large number of Crookes and Geissler tubes which had been displayed by GEISSLER. These tubes not only added interest to the lectures in physics during the following years but one of them was used for the first medical x-ray photograph made in the United States. One morning in January, 1896, PROFESSOR MILLER read in the newspaper of ROENTGEN's discovery of x-rays. That afternoon he had set up one of the Columbian Exposition discharge tubes and an induction coil and had taken his first x-ray photograph, that of MRS. MILLER's hand. The same year, in collaboration with DOCTORS GEORGE CRILE, HARLAN POMEROY and WESTON PRICE, of Cleveland, he took x-ray photographs of broken bones, of a bullet lodged in a boy's knee, and of impacted teeth. These early photographs are remarkably clear and sharp. With MRS. MILLER's help he also made a full-length self-portrait by means of x-rays. This was accomplished by taking nine separate photographs of the parts of the body and cutting the glass so they could be fitted together into a complete figure. During this period he gave many public demonstration lectures on x-rays.

In the summer of 1896 the MILLERS, accompanied by PRESIDENT STALEY and MRS. STALEY, made their first trip to Europe. This was a memorable tour, including a visit to CROOKES in England and to ROENTGEN in Wurtzburg. They saw ROENTGEN'S x-ray apparatus and he told them how he had blundered onto the discovery with his fluorescent screen. They made their first trip to Bayreuth for the Wagnerian Festival, a pilgrimage which they repeated many times in later years. In all, the MILLERS made 12 trips to Europe.



Professor Miller making an x-ray photograph at Case in 1896.

During these first years at Case the MILLERS lived in the same apartment house with PROFESSOR and MRS. E. W. MORLEY of Western Reserve University. They took all their meals together in the dining room downstairs, and spent every Sunday evening in conversation about the affairs of science and their mutual cultural interests. One of these discussions was concerned with the organization of the National Bureau of Standards. The directorship of this was first offered to PROFESSOR MICHELSON who declined and suggested MORLEY in his stead. MORLEY considered it carefully but likewise declined, and then he and MICHELSON talked the matter over and decided to recommend DR. S. W. STRATTON, who accepted the post. Dr. W. W. COBLENTZ, one of PROFESSOR MILLER'S first students in the course in physics at Case, joined the Bureau of Standards at this time and is now Chief of the Radiology Section.

In 1900 the MORLEYS and MILLERS went to Paris to attend the meetings of the International Science Congress. These were perhaps the most inspiring scientific meetings in the career of PROFESSOR MILLER. There he met LORD KELVIN, at whose urgent insistence MORLEY and MILLER repeated the interferometer experiment that MICHELSON and MORLEY had first performed in 1887 on the campus at Case and Western

Reserve. This partnership lasted several years, MILLER making all the observations and MORLEY planning and calculating the experiments.

From their earliest days at Case the MILLERS traveled widely, especially to scientific meetings and operatic performances and to visit relatives in the East and in California. They attended the first performance of the opera, *Parsifal*, in America, and to do this made a hurried trip from the Christmas meetings of the American Association for the Advancement of Science in St. Louis to New York. *Parsifal* was always PROFESSOR MILLER'S favorite opera. He heard it performed 23 times, and it was the last opera he attended, in February, 1940, at the time of the New York meeting of the American Physical Society.

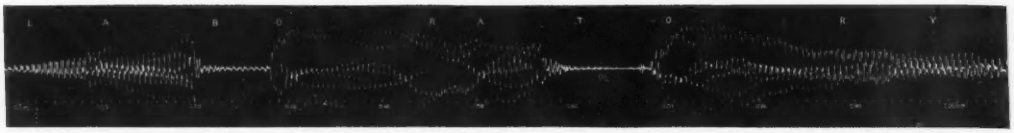
His love and understanding of music were deep and profound. He composed 31 pieces for voice, flute and piano, was an expert performer on the flute, pipe organ and piano, and had a thorough knowledge of the literature of music. His chief delight was in chamber music for the flute and piano, and at many Case assemblies in the earlier years he played the flute with MRS. MILLER accompanying at the piano. He admired all the Wagnerian operas and cut player piano rolls for these operas himself, using the full operatic score. One of the highlights of a visit to the MILLERS' home was to hear him play the Prelude, the song of the Rhine-maidens and the Entrance into Valhalla from *Das Rheingold*, or the Funeral March from *Die Götterdämmerung*. His piano was a special one with which he could produce remarkable effects. Among symphonies his favorites were the first movement of the TSCHAIKOWSKY Sixth and the slow movement of the Ninth Symphony of BEETHOVEN. His ideal for a perfect piece of music was the Prelude to *Lohengrin*.

In 1902 PRESIDENT STALEY retired and CHARLES SUMNER HOWE became the second president of Case. His interest in physics and fundamental science was profound and his support of PROFESSOR MILLER'S work was unstinting. Two years after he became president he secured the funds from JOHN D. ROCKEFELLER for the erection of the Rockefeller Laboratory of Physics. This building was planned by PROFESSOR MILLER and its equipment was purchased by him during a special trip to Europe in 1905. The building was constructed by the Austin Company of Cleveland, whose president, W. J. AUSTIN, was one of MILLER'S early students at Case. MR. AUSTIN maintained a deep interest in Case School and the activities of PROFESSOR MILLER throughout his life.

One of the special features of the equipment purchased was a very complete set of lecture apparatus for the general course in physics. These lectures were always one of PROFESSOR MILLER'S major interests at Case, and all the graduates of the college remember the beautiful demonstrations of sound, light and electricity which he made with original apparatus. In his ability to make the facts of science live he was a supreme artist. About a year ago a past president of the Case Alumni Association told me that the most vivid memory of his academic work in college was MILLER'S lecture in which the Michelson interferometer was used to show the torsion produced in a 4-in. steel shaft by a slight twist of the fingers. His interest in teaching methods and apparatus for the general physics laboratory was always keen, and his book on *Laboratory Physics* (1903), was a standard work for many years.

About 1906 MILLER'S interest in sound developed into full research activity. The phonodeik dates from this period. The word *phonodeik* was suggested by PROFESSOR MORLEY, and the first form of this instrument was demonstrated in 1908 before the American Physical Society in Baltimore. That summer it was also shown at the meeting of the British Association in Winnipeg, where MILLER first made the acquaintance of PROFESSOR J. J. THOMSON, who invited him to come to England and exhibit the phonodeik. In the development of the phonodeik, the theoretical problems involving minimum moment of inertia, resonant frequencies and other factors were the subject of the senior thesis of one of MILLER'S students, EDWIN C. KEMBLE, now Chairman of the Department of Physics at Harvard University.

The phonodeik aroused great interest in the scientific and technical world and among the general public as well. PROFESSOR MILLER began at this time an extensive American series of popular lectures on the phonodeik, and in the



Phonodeik record of the word, "Laboratory," spoken by Professor Miller.

summer of 1912 the instrument was taken to Europe for a series of demonstration lectures. For this visit MILLER had prepared phonodeik photographs of the spoken names of certain scientific celebrities he planned to visit, including J. J. THOMSON and JOSEPH LARMOR. THOMSON invited him to present before the British Association meeting at Dundee a paper on "The Registration and Analysis of Sound Vibrations." LARMOR asked him to describe the method of correcting the phonodeik records for horn and diaphragm response at the meetings of the Mathematical Society held at Cambridge that year. He lectured in Paris and at numerous places in Germany and gave phonodeik records of "Kaiser Wilhelm" to his German scientific friends. After he had returned to England and made his reservations for the voyage home, he received a special invitation from KAISER WILHELM to give the phonodeik lecture in English at the Royal Palace in Berlin. He promised to return in a few years to give the lecture but the World War intervened.

For many years PROFESSOR MILLER was consultant for the Aeolian Company, conducting research in its development of the Webber piano. He was responsible for the player-piano being built with 88 notes instead of the usual 65, and he himself purchased the first grand piano to be equipped with the player mechanism. The idea of accent notes was suggested by MILLER. These are produced by opening a valve with the right foot pedal so that the vacuum acts directly on the key mechanism. He delighted to show his friends the effect by playing BEETHOVEN'S "Moonlight Sonata." He also made experiments that were fundamental in the improvement of the sounding board. This work continued actively until broken off by the World War. Many of his suggestions for improving the Webber piano are now incorporated in other makes.

During the summer vacation of 1917 he used the portable phonodeik to study fog signals on the St. Lawrence River at Father Point, Quebec. It was also used to investigate the tone quality of many musical instruments, especially the flute. From a study of the effect of wall material upon tone quality, he became convinced that a flute made of gold would be the ultimate of perfection. Soon a lucky chance gave him the opportunity to secure the gold and construct the instrument himself. In New York a dentist had examined a patient's mouth with x-rays, and overexposure had resulted in a bad burn. MILLER testified concerning the physics of this case and his fee enabled him to buy a gold tube for the construction of the flute. He made an entire set of special tools to fashion the parts, and before assembly there were 392 separate pieces. It is a true work of art, a product of superb craftsmanship and technical skill. He always felt that the tone quality of this flute was superior to that of all others. Regarding this, MICHELSON once said: "When Professor Miller plays on a silver flute he is an accomplished flutist, but when he plays on his gold flute he is an inspired flutist."

In 1922 MILLER'S translation of BOEHM'S book on *The Flute and Flute-Playing* was published. This labor of love was accomplished during summer vacations.

One of his fundamental studies made with the phonodeik related to the characteristics of vowels. This work showed for the first time that each vowel tone is associated with certain resonant volumes in the head and was the first experimental confirmation of the fixed-pitch theory of HELMHOLTZ. The studies of musical instruments and the phonodeik records led him into the subject of harmonic analysis. He purchased a beautiful Henrici type analyzer from CORADI in Switzerland, and had constructed in the shops at Case a synthesizer patterned after the Kelvin tide-predicting machine. This synthesizer has been copied and extended in several important laboratories in this country. In 1917 the Franklin Institute awarded him its Longstreth Medal of

Merit in recognition of these contributions to harmonic analysis.

In 1914 PROFESSOR MILLER was invited to give the Lowell Institute Lectures in Boston, later published as his book, *The Science of Musical Sounds* (1915). During the course of these lectures, the MILLERS were the guests of PROFESSOR and MRS. WALLACE CLEMENT SABINE of Harvard University. The friendship between MILLER and SABINE was close and fruitful. MILLER'S interest in the subject of architectural acoustics dated from this time and, when SABINE'S work was stopped by his untimely death, MILLER became the principal advocate of good acoustics from that time until the development of commercial interest in this subject about ten years later. Among the buildings for which MILLER specified the acoustical treatment were the University of Chicago Chapel, the Princeton University Chapel, the Chapel of Bryn Mawr College, the Epworth Euclid Methodist Church in Cleveland, and Severance Hall, the home of the Cleveland Orchestra.

During the first World War MILLER made notable experiments at the Sandy Hook and Aberdeen Proving Grounds. To study the pressures developed in the vicinity of large guns in action he invented the instrument called the *baroscope*. To determine the shape of the sound waves and pressure waves of guns, he used the portable phonodeik. He also made a precise determination of the speed of sound in free air. This latter measurement is especially significant because of the level character of the terrain, the accurate meteorological data available, the great height of the microphones above the ground and the large distances between microphones. In the laboratory at Case he also made many spark photographs of bullets in flight. The details of this war work are described in his book, *Sound Waves: Their Shape and Speed* (1937). It is interesting to note that the photographic supplies used by MILLER in these war researches were brought over by the German submarine, Deutschland, on its startling trip to New York Harbor in 1916.

After the war MILLER received the very generous support of MR. ECKSTEIN CASE which enabled him to repeat the interferometer experiment at Mt. Wilson, California. The invitation to perform this experiment near the 100-in. telescope had been extended by DR. GEORGE ELLERY HALE. The experiments were carried on both at Mt. Wilson and at Case over a period of several years and the final results of the 250,000 individual readings made personally by MILLER are summarized in his paper in the *Reviews of Modern Physics* for July, 1933. At the Kansas City meeting of the American Association for the Advancement of Science in 1925 he was awarded the $1000 prize for this work. He also gave a series of special invited lectures on this subject before the Royal Society in London in 1926.

PROFESSOR MILLER was very active in scientific societies. He was vice president of Section B of the American Association in 1907, and was elected to the American Academy of Arts and Sciences in 1914, to the American Philosophical Society in 1919, and to the National Academy of Sciences in 1921. In 1918 he was made secretary of the American Physical Society at a meeting of the Council at MICHELSON'S home at the time of the Chicago meeting. After serving his term (1918–1922) in this office he became, successively, vice president (1923–1924), president (1925–1926) and finally member of the council (1926–1941) of this society. For the years 1927–1930 he was chairman of the Division of Physical Sciences of the National Research Council. In 1926 AMBROSE SWASEY founded the Ambrose Swasey Professorship of Physics at Case because of his own deep personal interest in PROFESSOR MILLER and his work.

MILLER'S lifelong hobby was the flute and all matters relating to its history and development. The flute collection now numbers 1426 instruments, together with a very comprehensive collection of books about the flute, an extensive library of flute music, and many art works relating to the instrument. This collection was willed to the Library of Congress in Washington where it is to be placed on permanent exhibition along the general lines planned by MILLER and the authorities of the Library. In addition to the gold flute and Chinese flutes of jade and carved ivory, some of the more interesting specimens in the collection are a glass flute that belonged to PRESIDENT JAMES MADISON, a glass flute owned by the EMPEROR FRANZ JOSEPH OF AUSTRIA, another brought to America by JEROME NA-

POLEON, and a bass flute that was specially constructed for the première of the opera *Aïda* at Cairo. PROFESSOR MILLER felt that the bass flute should be used more in musical compositions. His specimens of this instrument were loaned on numerous occasions to symphony orchestras which did not own one.

In his later years MILLER's activities at Case were concerned largely with writing and lecturing. In this period he wrote the *Anecdotal History of the Science of Sound* (1935), the idea for which was suggested by a former student, PROFESSOR F. A. FIRESTONE, of the University of Michigan, and which was first given in part as an evening lecture at a meeting of the Acoustical Society of America in Ann Arbor. His address on "The Spirit and Service of Science," delivered at the Case Commencement in 1936, when he was given the degree of doctor of engineering and made Honorary Professor, was a summary of his basic philosophy of science and life. When conferring the honorary degree, PRESIDENT WILLIAM E. WICKENDEN said: "As a pioneer in acoustical science you have wrought long and fruitfully to bring it from the obscurity of the laboratory into the common service of men. In every note of music, in every spoken syllable truly heard, these very walls [Severance Hall] proclaim your mastery." His last book, *Sparks, Lightning and Cosmic Rays* (1939), grew out of the Christmas series of lectures for young people delivered at the Franklin Institute in 1937. During this period he used the phonodeik for making photographs for books on sound and for friends and acquaintances throughout the world who asked for records. One of these was for the book on *Science and Music* by SIR JAMES JEANS. It is characteristic of MILLER's method of work that the phonodeik record used on the jacket of JEAN's book is the best of 24 attempts to get the most artistic photographs for the purpose. MILLER was always a master of technic and his manipulative skill in handling the phonodeik, even during his last year, was remarkable. His technical skill in other lines was no less perfect. During the last month of his work at the college he made a beautiful silver soldered joint and turned an ivory piece on the jeweler's lathe for repairing one of his flutes. He died of a sudden heart attack on February 22, 1941, having worked at the laboratory the day before.

Professor Miller at the Case Commencement, June, 1939.

A year before PROFESSOR MILLER's death, on March 14, 1940, Case School of Applied Science held a special convocation in honor of his 50 years of service to the college. On this occasion a portrait of him was presented to the school by his former students and friends on the Faculty and Board of Trustees. In accepting the portrait for the college, PRESIDENT WICKENDEN said:

> We shall make a permanent place for this portrait in the Rockefeller Laboratory of Physics, a building which you, DOCTOR MILLER, planned with loving care, and to which your inspiring teaching and notable researches have added an enduring distinction. In years to come this portrait will be one of our shrines; many a busy teacher, many a man wrestling with a problem of research, many a student going about his daily tasks will pause before it, arrested by the personality of a man who loved truth, beauty and integrity with his whole heart, and will be inspired to carry on the torch which you have borne so nobly."

Perhaps his most valuable contribution to physics is the group of disciples who began studying under him in the course in physics at Case. Of this group, 25 have obtained the doctor's degree, six are chairmen of college physics departments, two are members of the National Academy of Sciences, one is director of

physical research for the Dow Chemical Company, one edits the *Journal of Applied Physics*, another edits *The Journal of the Acoustical Society of America* and another conducts the patent department of that journal, one has dedicated a standard work on vibration and sound to him, and another, a definitive work on quantum mechanics. All carry his tradition of thoroughness into many lines of university, industrial and government research. It is most fitting that Case School of Applied Science has just established the *Dayton C. Miller Research Fellowship in Physics* so that other young men may follow in the traditions he established and, like him, may dedicate their lives to the spirit and service of science.

Addresses and Publications of Dayton C. Miller

The letter (A) signifies an abstract; the letter (T) that the title only appears in the periodical indicated.

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"Note on the electric conductivity of certain specimens of glass with reference to their fitness for use in static machines," Proc. A.A.A.S., Detroit **46**, 103 (A) (1897); Science **6**, 219 (T) (1897).

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"Exhibit of an automatic mercurial air-pump designed by Professor E. W. Morley," Proc. A.A.A.S., Boston **47**, 137 (T) (1898); Science **8**, 532 (A) (1898).

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A Laboratory Experiment on Luminous Intensity

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A PREVIOUS paper[1] described the use of a photoelectric photometer in studying the luminous flux from a tungsten-filament lamp as a function of temperature. The present article extends this work to a study of luminous intensity in a horizontal plane.

As shown in Fig. 1, a lamp socket is mounted on a turntable capable of motion over a graduated circle. One foot from the center of the lamp is placed a foot-candle meter of the dry-disk photoelectric type. From the illumination equation, $E=(I/d^2)\cos\theta$, it is easily noted that, for normal incidence, and with an illumination meter calibrated in foot-candles, the luminous intensity is in this experiment numerically equal to the meter reading. It is desirable to recheck the illumination meter periodically against standard lamps, to guard against changes in calibration. A voltmeter and wattmeter are also read along with the illumination meter.

While the lamp voltage is kept constant with the aid of a Variac transformer and auxiliary rheostat, the lamp is turned in 10° steps through a complete rotation, and the various meters are

[1] S. C. Gladden, Am. J. Phys. (Am. Phys. T.) **5**, 211 (1937).

TABLE I. *Values of voltage ratio factor k.*

LAMP	HANDBOOK*	EXPERIMENT
Carbon	5.62	6.1
Mazda C	3.38	3.3
Type D		3.2

* Pender and Del Mar, *Electrical engineers' handbook* (Wiley, ed. 3), p. 15–11.

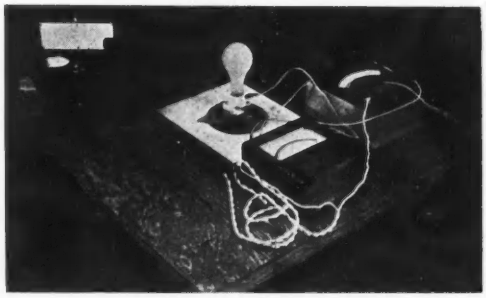

FIG. 1. Photograph of the apparatus.

read for each lamp position. The lamp voltage is then changed, and the procedure repeated. Four different types of lamps were used: a 32-cp, 110-v carbon, a 100-w, 120-v Mazda C, a 60-w, 115-v Mazda C, and a 60-w 115-v type D.

Among the various graphical results obtainable may be mentioned the distribution of luminous intensity of a particular lamp at different voltages, and the comparison of the distribution of luminous intensity at a particular voltage for the Mazda C and type D lamps of the same wattage. Lack of space prevents inclusion of typical curves of these types.

It is possible also to determine the voltage ratio factor for the different lamps, using the well-known equation,[2]

$$I_1/I_2=(V_1/V_2)k,$$

in which I_1 and I_2 are the intensities for lamp voltages V_1 and V_2, respectively, while k is a factor whose value depends on the type of lamp employed.

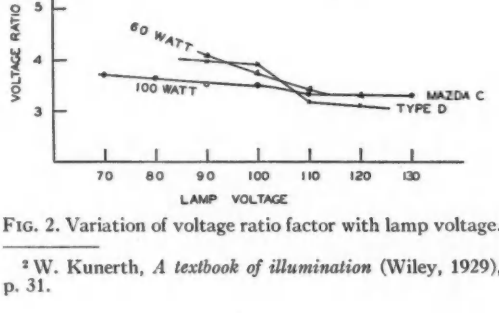

FIG. 2. Variation of voltage ratio factor with lamp voltage.

[2] W. Kunerth, *A textbook of illumination* (Wiley, 1929), p. 31.

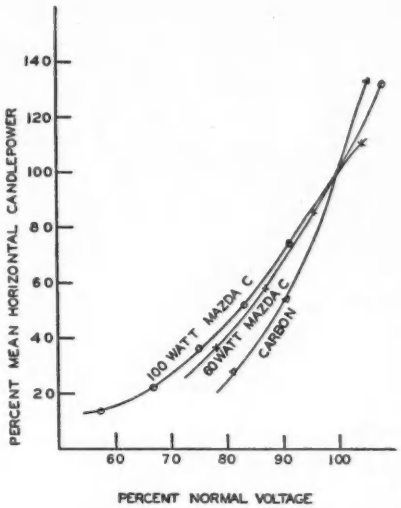

FIG. 3. Variation of mean horizontal candlepower with lamp voltage, expressed in percentage of normal values.

Using the mean horizontal candlepower for the particular voltage concerned—that is, the average of the 36 illumination meter readings—one may compute the voltage ratio factor k with reference to the luminous intensity at normal voltage. The variation of this factor with changes in operating voltage may be seen in Fig. 2. For the region of normal voltage, Table I is of interest. The experimental value of k for the carbon lamp is seen to be higher than the handbook value. The lamp used, however, was of an old type, and according to Kunerth,[2] the value of the factor is higher in that case than for more recent types.

Figure 3 illustrates another way in which the data may be plotted.

Although the experiment is not of the precision type, it has the advantage that the instruments used are available in the ordinary laboratory, and yet the data check remarkably well with results obtained with equipment of greater precision.

The Relation of Physics to Philosophy

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So that if we were to hold on to the letter of what metaphysicians and scientists say, and also to the material aspect of what they do, we might believe that the metaphysicians have dug a deep tunnel beneath reality, that the scientists have thrown an elegant bridge over it, but that the moving stream of things passes between these two artificial constructions without touching them.[1]

SINCE the subject of this paper takes in two immense bodies of knowledge—physics and philosophy—it will be impossible to give a complete account of their relations to each other. Consequently our inquiry will be limited to very general, but fundamental, considerations.

I. The Problem of Today

Separation of physics and philosophy

One of the outstanding characteristics of our modern age has been, and to a large extent still is, the divorce of the sciences from philosophy. This separation is a fact, whatever its historical cause or causes may be, whether the lack of the true philosophical and scientific spirit on the part of the philosophers, or the fascination that the new scientific method and its success have held for its devotees.

The modern man has been influenced by the method and onward march of science; he has been captivated by the certitude and mathematical exactness of its findings. The impressive success of the scientific method and its extensive progress led not only to the neglect of philosophy but at times to the total rejection of what was once the queen of disciplines.

Science, with its minute and exact observations and measurements, with its seemingly closer relation to vital reality and practical life, came to be considered as solely possessed of truth and certitude. Philosophy was relegated to the domain of fiction and of shadowy, meaningless speculation; it was regarded as dealing with conjecture and not with certitude—a matter of emotion, of likes and dislikes, or of blind instinct.[2] Such an attitude represented, of course, the extreme development of this separatistic evolution, where there was no longer mere separation but actual hostility. It is the attitude known as *positivism:* the affirmation of science and its method and the negation of philosophy.

Cause of this separation

It is a sign of the limitation and finiteness of man that, when he concentrates on one thing, he loses sight of other things, at least for a time. The modern man, in concentrating on the investigation of the universe according to the new scientific method of observation, neglected the truths that man had already learned, not through scientific methods, but through other, equally valid methods.

Popular writers make statements such as this: "Man has learned more about the earth in the last 100 years than in all the thousands of years of his existence before that time."[3] True! But during that same period man has lost sight of all, or most, of what man had achieved in the way of truth throughout those thousands of years.

Aristotle would have been the last to approve the Arabian attitude of considering him as the final authority in human science, just as Thomas Aquinas would not have countenanced the misguided adulation on the part of some of his followers, who thought that in his case there was no room for further progress. Both Aristotle and Thomas Aquinas looked upon the acquisition of knowledge as the task of the whole human race, not of one man or of one period. Each man, each age makes its contribution, but only a contribution, which must be assimilated and coordinated with the store of knowledge that other men and other ages have accumulated.

By reason of the complexity of reality and of truth, it is possible to go off on a tangent, to

[1] Henri Bergson, *An introduction to metaphysics*, tr. by T. E. Hulme (Putnam, New York, 1912), p. 80.

[2] Cf. Rudolph G. Bandas, *Contemporary philosophy and Thomistic principles* (Bruce, New York, 1932), p. 83.

[3] William Ferguson, "This curious world" (Pittsburgh Press, Apr. 3, 1941).

concentrate almost exclusively on some one aspect for a shorter or longer period of time. In this concentration, other aspects are neglected, with the result that great progress is made in relation to the given aspect.

Something of this sort is what has happened in our modern age; it has concentrated on one aspect of reality and has made astonishing advances. It has, however, neglected to refer those new achievements to the other aspects of reality that former ages investigated, and to the other aspects of truth that they attained, especially in the field of philosophy.

Need and means of unification

Of late there has been noticeable a movement to correct the mistake of this separation, which really derives from mutual neglect and misunderstanding. Men are beginning to realize, vaguely at least, that, on the one hand, science alone cannot satisfy human needs, whereas, on the other hand, philosophy alone does not give a complete picture of reality. There is, moreover, a growing conviction of the need for such coordination and unity.

Man has come to see that if both science and philosophy are valid bodies of knowledge, there must be some way of coordinating and unifying them. Our modern age must then find the proper place for this new knowledge, coordinating it with the fund of knowledge that is already the common property of the human race.

Since both science and philosophy are very complex, coordination will be effected only through patient, honest cooperation and hard-thinking discussion. One cause of the separation of science and philosophy was precisely their failure to communicate with each other. There was on the part of the philosophers a disdain for the analytical data of the sciences, and a similar attitude on the part of the scientists in regard to the synthetical truths of philosophy. The lines of communication and of mutual understanding must be re-established, a task that cannot be performed in a day, for it supposes that the philosopher is at home in the domain of science and that the scientist understands the validity of the methods and of the conclusions of philosophy. Perhaps centuries may be required to perfect this coordination, but the movement is under way.

The desired coordination will be completed only when all the achievements of science can be appraised and retained without sacrificing any of the achievements of philosophy, only when the truths of philosophy can be retained without losing any of the genuine advances in knowledge that science has contributed.[4]

II. Physics and Philosophy as Knowledge

Before we consider the foundation of this coordination in regard to our special subjects—physics and philosophy—it is necessary to remark that science is not considered here as a technology, as an application of physical principles in machines and appliances, but as *knowledge*, which, after all, is the foundation of and the prerequisite for technological application.[5]

It is true that much of man's knowledge has been acquired through the pressure of practical necessity. Man lives in intimacy with the forces of nature and depends on them to a large extent for his maintenance; in many cases, consequently, necessity has furnished the inspiration for in-

[4] Cf. Mortimer J. Adler, "God and the professors," *Science, philosophy and religion*, a symposium edited by the Conference on science, philosophy and religion in their relation to the democratic way of life, Inc. (New York, 1941), pp. 120–138.

[5] Read what Aristotle has to say on the subject: "The animals other than man live by appearances and memories, and have but little of connected experience; but the human race lives also by art and reasoning. Now from memory experience is produced in man; for the several memories of the same thing produce finally the capacity for a single experience. And experience seems pretty much like science and art, but really science and art come to men *through* experience; for 'experience made art,' as Polus says, 'but inexperience luck.' Now art arises when from many notions gained by experience one universal judgment about a class of objects is produced . . . we think that *knowledge* and *understanding* belong to art rather than to experience, and we suppose artists to be wiser than men of experience (which implies that Wisdom depends in all cases rather on knowledge); and this because the former know the cause, but the latter do not. For men of experience know that the thing is so, but do not know why, while the others know the 'why' and the cause. Hence we think also that the master-workers in each craft are more honourable and know in a truer sense and are wiser than the manual workers, because they know the causes of the things that are done . . .; thus we view them as being wiser not in virtue of being able to act, but of having the theory for themselves and knowing the causes. And in general it is a sign of the man who knows and of the man who does not know, that the former can teach, and therefore we think art more truly knowledge than experience is; for artists can teach, and men of mere experience cannot." *Metaphysics*, bk. I: chap. 1, 980b, 25 ff.; 981a, 24 ff. [*The basic works of Aristotle*, edited and with an introduction by Richard McKeon (Random House, New York, 1941), pp. 689 f.].

vestigation and the incentive for seeking knowledge. But even aside from practical necessity and practical application, man has an innate *desire to know*, an innate *curiosity*. Curiosity, or the desire to know, is at the foundation of inquiry, and apart from its practical applications, mere knowledge is an end in itself: man desires to know merely for the sake of knowing, for the sheer pleasure and satisfaction that knowledge gives him.[6] It is in this respect, as *knowledge* of reality, that physics and philosophy are here compared.

III. Relation of Physics and Philosophy

Foundation of the relation

Our question is, then, the relation of physics and philosophy in its fundamental aspects, or the foundation of that relation. That foundation is had in what may be called *ontological and epistemological pluralism;* namely, the complexity or plurality of aspects on the part of the objective reality that is to be known (ontological pluralism), and a complexity or plurality of valid ways of knowing reality (epistemological pluralism).[7]

Respective objects

In the case of both physics and philosophy, the object to be known is *reality*, and fundamentally the reality of the universe. Whatever can be known through human investigation may be considered as nothing more than an aspect of this universe.

Physics investigates the observational aspects of the universe; philosophy investigates the aspects that lie beyond the observational plane. If the first be called the physical aspect, the second may be called the ultra- or meta-physical; namely, the aspect that lies beyond—or behind—the sphere or possibility of observation.

Respective procedures or ways of knowing

This statement will become clearer from a consideration of the procedure proper to each type of inquiry. The sciences consider the observational aspects of things, aspects that are observable by the senses. That does not mean that *reason* is excluded; on the contrary, reason is at work in every science, since the object of every science is the *universal and necessary* as distinct from the individual and contingent. Observation notices only individual cases; it is reason that universalizes what is observed, abstracting from the individual cases. It is reason, working in conjunction with the observations made, that finally formulates the law by abstracting from the particular concrete cases and establishing a general universal law that applies to all cases of that kind.

Reason, therefore, enters into the work of the physicist, but the universal law that it formulates regards the observational aspect of reality; the only function reason has is to abstract that law from this or that particular set of observations. Reason's object is, therefore, the same as that of the senses; namely, the observable phenomenon as abstracted from the concrete individual phenomena.[8]

In philosophy, there is an entirely different procedure. There, too, observations are made; there, too, reason is employed, but in philosophy reason goes beyond the observational to the ontological, to something, namely, that can in no wise be the object of observation or of experiment. It knows the super- or ultra-observational, the purely *intelligible*.

In philosophy, just as in physics, this reasoning function is intimately joined to observation.

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[6] Wonder, according to Aristotle, is at the foundation of inquiry, because "it is owing to their wonder that men both now begin and at first began to philosophize; they wondered originally at the obvious difficulties, then advanced little by little and stated difficulties about the greater matters. . . . And a man who is puzzled and wonders thinks himself ignorant . . .; therefore since they philosophized in order to escape from ignorance, evidently they were pursuing science in order to know, and not for any utilitarian end. And this is confirmed by the facts; for it was when almost all the necessities of life and the things that make for comfort and recreation had been secured, that such knowledge began to be sought. Evidently then we do not seek it for the sake of any other advantage. . . ." *Metaphysics*, bk. I: chap. 1, 982b, 12 ff. (*ibid.*, p. 692). Cf. Theodor Wulf, *Modern physics*, tr. by C. J. Smith (Dutton, New York, 1929), p. 1.

[7] Epistemological pluralism may be understood better from its opposition to epistemological *monism*, which asserts that man has only *one* valid method of reaching certitude and truth, usually the positivistic method. Monism would not necessarily deny that there may be a plurality of aspects on the part of objective reality, but it does assert that man can have certitude in regard to only one aspect, the positivistic. Cf. Y. Simon, "La science moderne de la nature et la philosophie," *Revue néoscolastique de philosophie* (Louvain, 1936), vol. 39, pp. 64 f.

[8] Even when a scientific law or principle regards something that cannot actually be observed, the object remains within the field of observation: it is something *observable*.

There is a difference, however, in that, in physics, this function is a mere generalization of empirical phenomena, wherein the object of reason is exactly the same as that of observation, only universalized; in philosophy, it is a function whereby reason, basing itself on the observation of the senses, comes to know something beyond the observational, something that is not observed and, moreover, cannot be observed.[9]

In the case of heat and expansion, for example, both the intensity of the heat and the greatness of the expansion are observable and measurable phenomena; the physicist applies his reason to his observations, generalizing the phenomena and formulating their laws. The philosopher, considering these same facts and applying reason to them, comes to know something that is not and cannot be observed.

The sense observations note only the empirical phenomena:[10] *b* following *a* (expansion following application of heat). Using these observations, reason comes to know the existence of causality between *a* and *b*, the existence of finality or of a tendency within *a* always to produce *b*; reason here knows what lies beyond or behind the observed phenomena. Its operation is, however, based on the observations; it may be called the intellectual or rational interpretation of observations.

Relation of objects and procedures

It is natural for man to arrive at these purely intelligible realities through the observational, since knowledge, for man, has its source in the observations of the senses and is based thereupon. This is what may be called the *intellectual empiricism* of Aristotle and Thomas Aquinas. It shows the necessity of sense observations for intellectual life. Man's ideas are not innate, nor are they created by the intellect independently of the senses. Without sense observations, there are no ideas, and if man wishes to form a correct idea of the intelligible aspects of the universe, he must continually return to observation. However, these sense observations are used only as a basis, as a springboard to what lies beyond the observed phenomena.[11]

The relation and coordination of physics and philosophy are therefore based on the objective fact that reality is complex in its aspects, and the subjective fact that there are different valid methods of knowing these different aspects of reality.

Coordination of physics and philosophy illustrated

An example may serve to clarify further this relation as thus far described; at the same time, it will bring to light other aspects of the relation between science and philosophy, such as their mutual independence, the stability of philosophical principles and truths amid the continuous changes of scientific explanations, the clarifications given to philosophy through scientific progress.

The example is that of a *motor*. An ordinary attentive though superficial observation suffices to show that the various parts of a motor—*a*, *b*, *c*, *d*, and so forth—have different constitutions and different functions; it shows, too, that *a* moves *b*, *b* moves *c*, and so forth.

The ultra-observational aspects

Reason, considering these observations, knows something that lies beyond the possibility of

[9] Reason in philosophy may be called *super-positivistic* in opposition to merely *positivistic* reason as used in the sciences. Cf. Y. Simon, reference 7.

[10] ". . . a registration of the co-existence and sequences of sensible phenomena." E. I. Watkin, *Philosophy of form* (Sheed and Ward, New York, 1935), p. 87.

[11] "As we have said above, our intellect's proper and proportionate object is the nature of a sensible thing. Now a perfect judgment concerning anything cannot be formed, unless all that pertains to that thing's nature be known . . . the natural philosopher cannot judge perfectly of natural things, unless he knows sensible things. But in the present state of life whatever we understand we know by comparison to natural sensible things. Consequently it is not possible for our intellect to form a perfect judgment, while the senses are suspended, through which sensible things are known to us." S. Thomas, *Summa theologica*, pars I, q. 84, a. 8 [*The "Summa theologica" of St. Thomas Aquinas*, literally translated by Fathers of the English Dominican Province (Benziger, New York, 1912), part I, third number, pp. 176 ff.] Cf. pars I, q. 84, a. 4 (*ibid.*, p. 166), where it is stated that it is evidently untrue that "a man born blind could have knowledge of colours." Cf. also pars I, q. 84, a. 7 (*ibid.*, pp. 173 ff.). However, "sensitive knowledge is not the entire cause of intellectual knowledge. And therefore it is not strange that intellectual knowledge should extend further than sensitive knowledge," pars I, q. 84, a. 6, ad 3 (*ibid.*, p. 173). In other words, "through such natures of visible things it rises to a certain knowledge of things invisible," pars I, q. 84, a. 7 (*ibid.*, pp. 174 ff.). But even in this case, "incorporeal things, of which there are no phantasms, are known to us by comparison with sensible bodies of which there are phantasms," pars I, q. 84, a. 7, ad 3 (*ibid.*, p. 175). Cf. Edgar de Bruyne, *St. Thomas d'Aquin* (Gabriel Beauchesne, Paris, 1928), pp. 231 ff.

observation: that *a* has a nature that differs from that of *b*, that *a* causes the movement of *b*, that *a*'s purpose is to cause *b*'s movement. Moreover, reason can conclude that, since the movement of each part depends on the preceding part, the movement does not and cannot start unless there is some initial motive power. From the same observations, it can be concluded that these various parts did not put themselves or one another together or determine their respective functions, but that, on the contrary, they must have been made and determined—or designed—by someone. From the same superficial observation of the motor itself, reason can obtain a knowledge of that design *as existing in the mind and intention of the designer*. In a word, reason working in conjunction with the senses, uses their observations as stepping stones to a knowledge of things that lie behind and beyond the observations as their intelligible background.

The observational aspects

If, afterwards, more accurate observations are made of the motor, a more detailed and more accurate knowledge of the constitution of its various parts can be obtained; the relations of their respective movements can be determined more accurately: *b*'s movement is seen to be augmented proportionately to *a*'s movement. These are more accurate details that clarify the originally superficial observations.

Relation of the two aspects

These new observations do not alter the knowledge that reason had obtained through the original superficial observations: *a* still differs from *b*; *a* still has causality in relation to *b*; the whole motor is still known as the result of a design and a designer; the initial motive power is still required to start it running.

In other words, the rational knowledge and conclusions based on the original observations remain intact, although it must be admitted that they become clarified through the new details of observation: *a* can now be more accurately distinguished from *b*; the relations of *a* and *b* are now known more precisely; since the motor itself is now known more accurately and more in detail, the original design as existing in the mind and intention of the designer becomes better known.

A study of the motor could then concentrate on the rational knowledge and conclusions as based on the superficial observations; on the other hand, it could neglect them and concentrate on an accurate, detailed observation of the motor and of its functionings. One does not necessarily involve the other, but they do clarify each other, and only when taken together do they give the complete picture of the motor.[12]

Physics, observation and philosophy

The example of the motor sheds light on the relation and coordination of physics and philosophy in their study of the universe, each concentrating on a different aspect according to a different method.[13]

The ancient philosophers observed the universe in a rather superficial way, as the motor was originally observed. This observation sufficed to give them a knowledge of differences of things, of causality and of finality; observation of the movement of one thing by another led them to deduce the existence of a Prime Mover; observation of design in the universe gave them knowledge of the existence of a design and of a Designer.

Although very superficial in comparison to our modern observations, those original observations were valid and a sufficient foundation for philosophizing.[14] Causality, finality, intimate natures, Prime Mover, Designer, cannot be the object of observation; they are the ultra-observational, or intelligible, aspects of the universe.

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[12] Compare this with St. Thomas' example of an apple, that for the eye is a color, for the nose an odor. No organ knows the object in its entirety. That an apple is known as a color, without odor, by the eye, is due to the fact that one sense alone does not know all the sensible aspects. It is, however, evident that color is a real aspect of the apple, although only one among many, isolated by the eye. In the same way, when the intellect knows a thing, it knows it in an abstract and universal fashion. The intellectual aspect of the apple, as essence, is as real as the colored aspect, but the fact that the apple is known as an essence only by the intellect, hence impoverished, is an accidental fact of intellectual operation. Cf. S. Thomas, *Summa theologica*, pars I, q. 85, a. 2, ad 2 (*ibid.*, p. 186), and pars I, q. 85, a. 1 (*ibid.*, p. 181). Cf. Edgar de Bruyne, reference 11, p. 112.

[13] What is here said regarding the relation of physics and philosophy applies also to the other observational sciences in relation to philosophy.

[14] Cf. Jacques Maritain, *An introduction to philosophy*, tr. by E. I. Watkin (Sheed and Ward, New York), pp. 118 f.

Physics' more accurate observations, and philosophy

The modern age has made much more accurate and detailed observations which supply more critical and more exact observational data. However, the philosophical principles remain unaltered; in fact, they are clarified by the new observational findings.

Man's store of knowledge has been greatly increased by these new investigations, but the findings must be coordinated with the old philosophical truths, especially those of Prime Mover as coming from Aristotle, and of Designer, the more metaphysical doctrine of Plato. As was previously mentioned, Thomas Aquinas looked upon the acquisition of knowledge and truth as a cooperative work of all men and all ages. He himself investigated the writings of all the ancient pagan philosophers in order to assimilate what they had found of truth. It was he who joined Aristotle's idea of Prime Mover to Plato's idea of Designer, having perceived that this world needs both a Prime Mover and a Designer in order that our observations may be made intelligible.

The *motor* would not be in existence if someone had not designed and made it; it would not run if there were no initial motive power. The *universe* would not be in existence if someone had not designed and made it; it would not be "running" if there were no initial motive force.

By reason of his more accurate observations, the physicist has means of clarifying these philosophical truths and of observing them in their more accurate details; without them, he deals with mere phenomena. The philosopher, without the detailed data of the physicist, has the general ideas and the general truths, but he ignores the details of their applications.

Physics and philosophy thus cooperate in giving us a complete knowledge of the universe. Distinct and independent[15] according to their methods and according to the aspects they consider, they are coordinated insofar as, on the part of the object, they give us a knowledge of aspects of one and the same thing—the universe; they are united, too, on the part of the subject—man—because they are but different ways in which one and the same man knows the universe.

IV. The Unity of Man and of Knowledge

It is not the senses that observe and know in one case—in physics—and the intellect that knows in the other case—in philosophy—but it is man who knows through the means of both. Since man is one, his knowledge is also a synthesis of observation and of intellectual knowledge.[16]

Since, too, man has an innate desire to know reality as fully as possible, he can never be satisfied with "physical" knowledge alone, all the more so since his reason naturally tends to philosophize about the observational data he accumulates as a physicist. As a physicist a man considers the observational field; as a philosopher, the same man tends to go beyond the observational field, precisely in order to have a rational—intelligible—background for it.

In the same way, the philosopher, or man as a philosopher, considers the intelligible aspects of the universe; the same man as a physicist desires to complete his knowledge and see the application of his philosophical principles in the detailed data of physics.

Neither has, alone, the complete picture of reality. It is only man who can have that complete picture of what reality truly is, through unifying and coordinating the knowledge that he has as a physicist with the knowledge that he has as a philosopher. Then, and only then, does man have within himself a complete replica of reality, a mental possession of it in all its aspects.

[15] Cf. Jacques Maritain, reference 14, p. 115: "From all we have just said it follows that to be proficient in the sciences it is not necessary to be a philosopher or to base one's work on a philosophy; neither need the scientist while engaged in his special task seek advice from the philosopher or attempt to play the philosopher himself; but 'philosophy alone enables the man of science to understand the position and bearings of his special science in the sum-total of human knowledge' or 'to acquire a notion either of the principles implicit in all experimental knowledge or the true foundations of the special sciences.' "

[16] Cf. S. Thomas, *de Veritate*, q. II, a. 6, ad 3; Edgar de Bruyne, reference 11, p. 243; Jacques Maritain, "Science, philosophy and faith," *Science, philosophy and religion*, reference 4, p. 176.

I know of nothing more hopeful for society than to combine a good engineering education with a sound philosophy.—W. S. Learned.

A High Frequency Induction Furnace and High Frequency, High Voltage Induction Coil

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THIS paper is a description of the construction of a combination high frequency induction furnace and a high frequency, high voltage induction coil. Both devices are serviced by a common oscillator circuit and power supply. The interchange from one type of apparatus to the other is accomplished by the switching of only four contacts. These contacts are "banana" jacks, and the time required for the change is approximately 20 sec. The project offers to the advanced student experience and training in solving a definite problem, and yields equipment useful for demonstrations, advanced experiments and research.

The Oscillator and Power Supply Circuits

The oscillator circuit (Fig. 1) is of the usual Hartley type. The current to the plate of each tube is in one-half of the oscillating coil N or L. The grid voltage, since it must be less than the total oscillating voltage and 180° out of phase, is obtained by means of a tap fairly close to the center of the coil and toward the opposite end from the tube which it serves. The impedance L/CR presented by the tuned circuit must be approximately correct for the tubes used. Because of the coupled-in resistance of the loading device connected to the coil, R is the apparent resistance of the coil rather than the actual resistance. The nature of this loading device depends upon whether the oscillator is serving the induction furnace or the induction coil.

The power supply (Fig. 2) is provided with a switching device to change the plate voltage in four steps from 1000 to 4000 v. Each power transformer is rated at 1300 v amp. An overload relay limits the plate current to 600 ma.

The Induction Furnace

The transfer of power from the oscillator circuit to the furnace circuit is accomplished through the loosely coupled coils N and N' (Fig. 1). For maximum power transfer and proper choice of impedance the characteristics of these coils were approximated from standard formulas and final adjustments were made experimentally: N is 14×4 in. and has 33 turns of $\frac{3}{16}$-in. copper tubing; N' is about 5 in. in diameter and has 2 turns of $\frac{3}{8}$-in. tubing. Although the heating circuit to be coupled to coil N may be either parallel-resonant or series-resonant, the former circuit offers some practical difficulties not presented by the latter. The arrangement adopted is illustrated by the loosely coupled circuit $N'C''N''$. The effective load resistance of this circuit is not shown in Fig. 1.

For such a resonant circuit the frequency f is equal to $1/2\pi(LC)^{\frac{1}{2}}$. The impedance can easily be

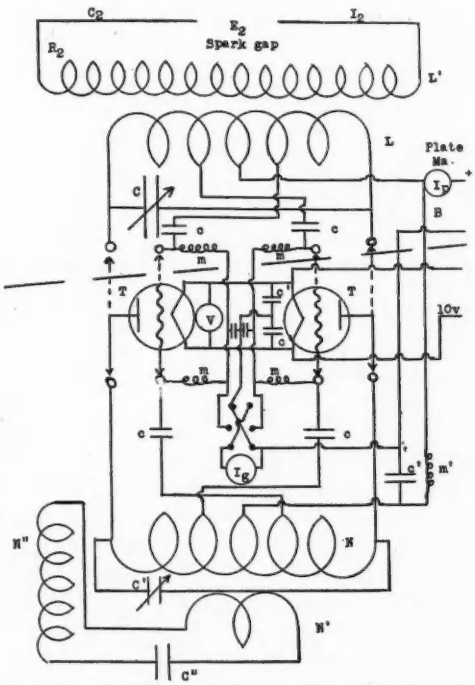

Fig. 1. Circuit diagram: L, L', primary and secondary for induction coil; $C=0.0005$ μf, 10,000 v; $m=4$ mh; T, Taylor T155 tubes; $c'=0.002$ μf, 5000 v; $m'=1$ mh; N'', furnace heating coil; C', furnace tuning condenser, 50 μf, 9000 v.

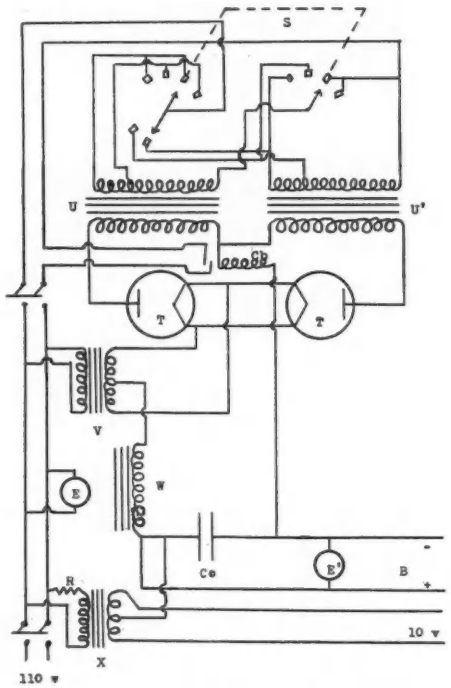

FIG. 2. Power supply: U, U', Thordarson transformers T7351; T, 866 tubes; Cb, overload relay, 600 ma; W, Thordarson choke 6316; V, Thordarson transformer 6433; Co, filter condenser, 1 μf, 5000 v; X, Thordarson transformer 6415.

matched by a correct choice of the number of turns on N', or by varying the coupling between N' and N. Since the impedance of this circuit is R, the current is E/R. In practice, R can be made very small; then the current is rather large compared to currents ordinarily obtained in radiofrequency circuits of moderate power. If it is assumed that the eddy current heating in a radiofrequency circuit follows approximately the same law as in circuits of low frequency, the heat W evolved will equal kLI^2f^2. Thus, for eddy current heating the inductance should be large and the capacitance small. This is a condition easily met, since the impedance of the series-resonant circuit is essentially independent of both.

THE INDUCTION COIL

The induction coil circuit is shown in Fig. 1 above the broken line. It consists of an oscillatory circuit connected in the plate circuit of the oscillators, and the coil of this circuit in turn coupled inductively to a long coil of many turns in which are induced the high voltage, high frequency currents. Comparatively simple theory shows that $E_1/E_2=k(L/L')^{\frac{1}{2}}$, where E_2 is the voltage across L' and E_1 is the voltage across L. If E_2 is to be high, L' should be large compared to L. This means that C_2 must be small compared to C. These conditions are not difficult to meet, because C_2 is the distributed capacitance of the secondary and is, therefore, quite small. Similarly, L' is the result of a long coil of many turns of small wire and, consequently, is rather large compared to L.

DETAILS OF CONSTRUCTION

The instrument is assembled on a table about 42 in. long, 24 in. wide and 42 in. high (Fig. 3). Two undershelves hold the heavier and more unsightly equipment and a sloping panel at one end contains the meters and control apparatus. The bottom shelf supports the elements of the power circuit, the series condenser for the furnace circuit and the larger condenser for the induction coil primary. On the middle shelf are the tuning condensers for both circuits. The controls for these condensers are on the right side of the table as one faces the instrument panel. On top of the table are mounted the oscillator tubes and coils, the respective grid chokes and blocking con-

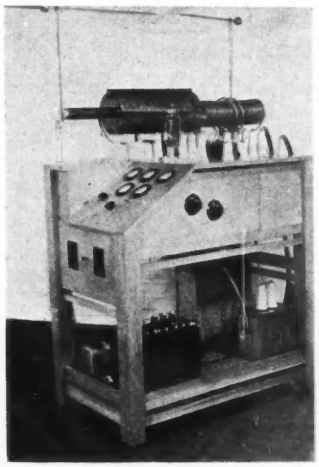

FIG. 3. General view of instrument.

densers. The instrument panel contains five meters which indicate the plate and grid currents and the plate, filament and line voltages. A rotary switch to change the plate voltage and a filament rheostat are also on this panel. Just below the panel are "On" and "Off" switches for filament and plate circuits and an overload relay to protect the power supply.

The series condenser (*C''*, Fig. 1) for the furnace must withstand about 50 kv. Tests showed that insulation against the high frequency voltages required a 1-in. gap. The condenser is built of 18-gauge galvanized iron. The box is $9\times6\times8\frac{1}{2}$ in. On its bottom are supported two vertical plates 6 in. high (Fig. 4); these are spaced 2 in. apart and welded to the ends of the box. The top of the box is a narrow metal rim holding a piece of Pyrex plate glass with two lead-through insulators mounted on it. From the bottom of these insulators is suspended a three-plate structure designed to fit between the box and the two welded-in plates and leave a 1-in. space on all sides and ends. The box is kept at low potential.

Of several liquids tried in this condenser, a grade of distillate slightly heavier than kerosene (specific gravity approximately 0.84) is the most satisfactory dielectric for the frequencies used. Dielectric and resistance losses in the iron are very low. Assuming a current of 25 amp in this circuit (which is certainly much too low, since one $\frac{3}{16}$-in. copper rod had insufficient conductance) a resistance of 0.6 ohm would account for 1000 w of power absorbed. Since no such absorption of power is observed, the resistance of the condenser is probably only a few hundredths of an ohm.

It is interesting to note that dielectric loss and dielectric constant must be given as much consideration as dielectric strength. For instance: glycerin, with a constant of 56 and a dielectric strength of, probably, 10^6 v/cm is useless for a condenser when operating at radiofrequencies. Such a condenser of plate area 2 in.^{2} and spacing $1\frac{1}{2}$ in. was connected across the oscillator coil of the furnace. The loss was almost sufficient to stop the tubes from oscillating. About 100 ml of the glycerin became quite warm in a few seconds of operation. Although this proved to be an extreme case, similar trouble was experienced with many other substances which were tried. In general, a substance with a dielectric constant larger than 4 or 5 will have a high loss in the radiofrequency range.[1]

[1] E. J. Murphy and S. O. Morgan, "The dielectric properties of insulating materials," Bell. Sys. Tech. J. **16**, 640 (1937); **17**, 493 (1938).

The parallel condenser (*C*, Fig. 1) for the induction coil requires a much larger capacitance and operates at a much lower voltage than that for the furnace. It is made of 12 9×12-in. parallel plates $\frac{1}{4}$ in. apart. This condenser is in parallel

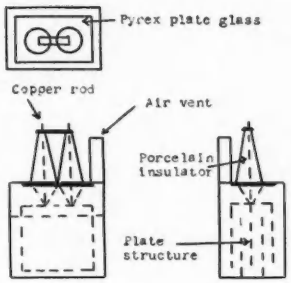

FIG. 4. Series condenser for furnace.

with a 50-μf, 9000-v variable condenser which is used in tuning. Both condensers have the same dielectric as that used for the furnace condenser.

The induction coil primary has 47 turns of $\frac{1}{4}$-in. copper tubing. It was first shaped to size on a 6-in. battery jar and then threaded on three Bakelite strips. These strips have holes drilled in them at $\frac{3}{8}$-in. intervals to hold the tubing rigidly in place.

The induction coil secondary consists of 5000 turns of No. 34 enameled copper wire wound on a 50-mm Pyrex glass tube 1 m long. The winding was done on a machine lathe, spacing the wire evenly 140 turns to the inch. The coil is mounted in the center of the primary coil by means of two 6-in. Pyrex insulators.

PERFORMANCE

The furnace.—Leads to the heating coil are cut from No. 00 welding cable. The coil most commonly used is 3 in. in diameter and has 15 turns of $\frac{5}{16}$-in. copper tubing. With a power input of less than 200 w the instrument will heat to a dull red, in free air, a hollow iron cylinder $\frac{1}{2}$ in. in diameter, 3 in. long and $\frac{1}{32}$ in. thick, with the input 800 to 1000 w, a solid iron rod $6\times\frac{3}{4}$ in. is heated to about the same temperature. In order to concentrate the flux around the object to be heated, it is convenient to have several heating coils of different sizes and shapes.

The induction coil.—The frequency of the

current from the secondary is about 300,000 cycle/sec. The corona discharge at the electrodes appears to have 6 or 8 "fingers" approximately 6 in. long. The sparks are 10 to 12 in. long and $\frac{1}{4}$ to $\frac{1}{2}$ in. in apparent diameter. The only physiological effect of the current is a slight feeling of warmth where the current enters the body. With this instrument one may demonstrate most of the experiments usually performed with such high frequency currents.

Training of Physicists for Defense Industries

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THE Engineering Defense Training (EDT) program for the fiscal year 1940–41 has been renewed for another year and has been extended to authorize the training of physicists, chemists and production supervisors, in addition to engineers, in fields essential to the national defense. The name of the program has been changed to *Engineering, Science, and Management Defense Training* (ESMDT). The relevant part of the new Act, Public Law No. 146, 77th Congress, 1st Session, approved July 1, 1941, is as follows:

> For the cost of short courses of college grade provided by degree-granting colleges and universities pursuant to plans submitted by them and approved by the Commissioner, which plans shall be for courses designed to meet the shortage of engineers, chemists, physicists, and production supervisors in fields essential to the national defense, and such plans may provide for regional coordination of the defense training program of the participating colleges and universities, $17,500,000: Provided, That only colleges and universities which operate under charters which exempt their educational property from taxation and public degree-granting educational institutions shall be eligible to receive funds herefrom: Provided further, That not to exceed 20 per centum of the amount allotted to any school shall be allotted to it for expenditure for purchase and rental of additional equipment and leasing of additional space found by the Commissioner necessary to carry out its approved plan.

In the Regulations Governing the Education and Training of Defense Workers pursuant to the Act promulgated by the U. S. Commissioner of Education and approved by the President, the term *degree-granting* is defined as follows:

> Degree-granting as used herein shall mean that the institutions, in recognition of satisfactory completion of a curriculum of four years or longer beyond high-school graduation, granted during the academic year 1940–41 degrees with a major in one or more of the following fields: engineering, chemistry, physics, or production supervision.

This definition applies either to graduate or to bachelor degrees. An undergraduate major in physics is taken to be a minimum of 18 junior-senior semester credit hours, or their equivalent, a substantial part of which require the calculus as a prerequisite.

To be eligible to give courses in physics, an institution must present evidence that it has a qualified staff and adequate facilities—for example, adequate laboratory equipment—that in the academic year 1940–41 it conferred degrees in physics conforming to the afore-mentioned standards, and that its educational property is exempt from taxation.

The Plan for Short Engineering, Science, and Management Courses, usually referred to simply as the "Plan," is an agreement between the Commissioner of Education and the institution, which defines the procedure to be followed in the conduct of the courses and expenditure of funds. It also contains the name of the institutional representative who will be responsible for clearing all matters relating to the ESMDT program at the institution; he acts as liaison officer between the institution and the Commissioner. When the Plan is approved by the Commissioner, the institution will be eligible to give ESMDT courses in those fields specifically enumerated therein. The final proposals, mentioned below, become an essential part of the Plan of the institution when they are approved.

An institution that expects to participate in this program should, first of all, establish its eligibility. The most expeditious way to handle this is to present at one time all the evidence for each of the fields in which courses are planned. An institution that participated in the EDT program last year is automatically eligible to give engineering courses in the ESMDT program, but its qualifications in physics, chemistry and production supervision must be approved before courses in those fields can be authorized. To determine the eligibility of an institution, the following special information must be available when its plan is considered: (1) number, training and experience of staff members; (2) laboratory facilities; (3) requirement for a major or field of specialization; (4) number of degrees conferred in 1939–40 and 1940–41 in each field, with bachelor and graduate degrees listed separately. A copy of the latest issue of the institution's catalog should be on file in the ESMDT office.

An eligible institution that wishes to give one or more courses should make a preliminary survey of defense training needs in its area to ascertain the types of courses needed and the probable enrolment. To avoid duplication of effort this survey should be made in cooperation with other institutions in the area. A preliminary proposal is then submitted for each course on a special form setting forth the defense need for the course, defense industries to be served, educational prerequisites, length of course, course outline, instructional staff with qualifications, probable maximum and minimum enrolment, and an itemized estimate of the costs of the course.

If the preliminary proposal is approved, the institution may begin instruction as soon as the course can be organized. If the actual enrolment is less than the minimum authorized, the course cannot be given, but the institution will be reimbursed for the costs incurred in making the effort.

A course may be organized in as many sections as the enrolment necessitates, and the different sections may meet in various locations according to the convenience of the class. Instruction in the various sections authorized by a single preliminary proposal may begin over a period of four weeks. After that, additional preliminary proposals will be required to take care of other sections.

After the last section authorized by a preliminary proposal has been in operation for a week, the institution submits a final proposal giving more accurate information than was possible in the preliminary, including cost estimates based on the actual enrolment at the end of the first week. If this proposal is in good order, funds are certified to the Treasurer of the United States who will send a check for the cost of the course, as given in the proposal, to the financial officer named in the Plan.

The "cost of the course" means the actual incremental cost to the institution due to the course. The budget is itemized under three headings: (1) Administration and supervision, (2) Instruction and (3) Building operation and maintenance, each one of which is subdivided into salaries, space or equipment, necessary staff travel, materials and supplies, and other expenses. If the institution finds it necessary, the cost estimates in the final proposal may be revised even after the proposal has been approved.

ESMDT courses are open to any person without restrictions as to creed, race, sex, color or national origin, who is employable in a defense activity or immediately available for such employment on completion of the course and who can meet the educational prerequisites of the course. Regular college students may not be admitted to ESMDT courses except in special cases approved by the Director.

Students must furnish their own textbooks, minor supplies and subsistence, but they pay no tuition fees since the Federal Government reimburses the institution for the cost of the course.

Courses are of two types—part-time courses for employed persons and full-time day courses. About 90 percent of the students in the EDT program were enrolled in courses of the former type. In the new program, the proportion will probably be about the same.

The content of the part-time courses should be carefully selected to meet the needs of the class. The training should be very specific, aiming to make the students more efficient in their immediate tasks or to prepare them for more technical and responsible positions. The

subject matter may range from general physics of sophomore grade to work at the graduate level. There is a widespread need in industry for courses of the grade usually given to engineers in the sophomore year, as well as for more advanced courses.

Full-time courses must be of upper-division or graduate level. Minimum prerequisites should be one year of general college physics and, in most cases, elementary calculus. The courses should be carefully planned to meet immediate needs in defense industries. At present there is a shortage of radio engineers of all grades and of persons with advanced training in the fields of electric circuits, vacuum tube devices of all sorts, conduction of electricity through gases, thermionics, photoelectricity, electromagnetic waves, especially short waves, geometrical and physical optics, hydrodynamics and aerodynamics. The emphasis should be on experimental technic designed to prepare students for laboratory work of a developmental and minor research character. Serious training needs doubtless exist in other fields but information concerning them is less definite.

The Act specifies that these courses shall be "short courses of college grade." To comply with this provision, most courses are less than 20 weeks in length, the majority probably around 14 or 16 weeks. Longer courses can be authorized under special circumstances which should be clearly explained in the preliminary proposal. Full-time courses are usually conducted so as to require a total of 45 or 50 hours per week of class work, laboratory and preparation. Part-time courses must be adjusted to the time available to the students but it is seldom profitable to require more than a total of 12 hours per week.

The recruiting of students is left entirely to the institution. Recruiting for part-time courses is usually not a very difficult matter in industrial areas where the enormous expansion has created a serious shortage of technically trained personnel. The procedure should be to confer with the proper executives at each plant who are familiar with their own training needs. Some persistence may be required since plant executives frequently display an amazing lack of imagination and foresight in estimating their present and future needs. To interest students in full-time courses recourse may be had to newspaper advertising, radio announcements, posters and letters to recent students.

Up to the present, most of the training has been on a local basis. Classes, for the most part, have been recruited from a restricted area and the instruction has been designed to fit the needs of defense industries in that area. This scheme is not likely to be adequate much longer. We must look forward to training students wherever we can find them, or at the nearest institution having adequate facilities, and then send them to defense industries that need them. In the case of physics, this procedure may be necessary from the start, on account of the limited number of suitable students available. The institution is not restricted to draw its students for ESMDT courses from a given region. The limiting factor is likely to be the ability of the students to pay their own subsistence and travel expenses.

College credit may be given for ESMDT courses, if the institution wishes to do so, but only a very few are doing it. These courses are not designed to turn out well-rounded physicists and engineers. They are an attempt to meet a specific defense need quickly and at a reasonable cost. To grant college credit for ESMDT courses would have a tendency to make them conform to ordinary college courses. On this account, opinion at most colleges is against giving credit.

Of the amount appropriated in the Act, $100,000 has been designated for physics. This amount is not fixed and can be changed later if training needs require. Furthermore, only courses of upper-division and graduate level will be charged to this amount. Elementary courses and courses leaning toward engineering—for example, general physics and most radio courses—will be charged to engineering. Funds, however, are definitely limited and approval of proposals will be determined by demonstrated defense need, prospects of placing students and facilities available for instruction.

All communications and requests for forms should be addressed to Dean Roy A. Seaton, Director, Engineering, Science, and Management Defense Training, U. S. Office of Education, Washington, D. C. After the institutional representative is appointed all communications should be made through him.

An Abridged Bibliography of Studies Pertaining to Physics Teaching

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THIS bibliography was compiled by the writer while working on a problem in the teaching of physics. The many studies that have appeared in the AMERICAN JOURNAL OF PHYSICS are not included here, since they are listed in the annual indexes of the Journal.

The author is grateful to Professor C. J. Lapp, who presented him with a list of 45 studies which are included in the bibliography.

GUIDE TO STUDIES[1]

Abilities, 8, 36, 41, 47, 48, 83
Achievement, 2, 7, 9, 20, 30, 43, 54, 59, 75, 82, 97, 104, 105, 114, 120, 128, 137, 138, 161, 167, 195
Aims, 28, 38, 45, 59, 148, 157, 177, 186, 195, 207, 231, 248
Apparatus, 31, 41
Character formation, 25, 35, 119, 143
Comparative education, 71, 86
Concepts, development of, 13, 19
Content, 43, 54, 75, 79, 95, 100, 101, 110, 116, 124, 132, 133, 134, 138, 140, 142, 144, 155, 156, 165, 167, 169, 197, 203, 213, 222, 237, 244, 254, 264
Cooperative experiments, 107, 131
Curriculum construction, 39, 46, 49, 60, 61, 76, 77, 79, 97, 100, 108, 109, 114, 116, 132, 133, 138, 140, 170, 198
Demonstration method, 3, 167, 175, 195, 199, 214, 240
Direct thinking, 15, 21
Drills, 7, 9
Efficiency, 5, 7
Equipment, 46, 61, 88, 111, 151, 155, 179, 184, 202, 243
Even-front system, 62, 78
Failure, 80, 101
History, 126, 150, 186, 211, 212, 252
Indoctrination, 82, 105
Industry, 184, 211
Intelligence, 80, 101
Interest, 72, 91
Integration, 139, 164, 172, 192, 193, 200, 203, 210, 229, 244, 250
Laboratory work or method, 62, 78, 88, 111, 127, 133, 137, 138, 151, 156, 162, 167, 195, 196, 199, 200, 232, 240
Lecture method, 3
Life experiences or activities, 23, 33, 59, 75, 86, 87, 93, 109, 110, 116, 184, 211
Marking, 48, 63
Mathematical ability, 7, 9, 14, 22, 38, 48, 79, 100, 140, 142, 144, 158, 162, 165, 167, 169, 176, 182, 189, 193, 210, 221, 215, 229, 250, 263
Mechanical ability, 83, 106
Mechanics, 6, 8
Methods of teaching, 3, 41, 51, 57, 72, 105, 107, 129, 131, 132, 155 167, 194, 195, 207, 230, 248
Motion pictures, 56, 70, 71, 89, 155, 175, 184, 214, 221, 264
Newspapers and magazines, 20, 30, 50, 65, 89, 97, 112, 121, 154, 165, 166, 183, 193, 194, 217, 220, 229, 257, 263
Outcomes, 58, 63, 68, 73, 80, 85, 96, 101, 119, 124, 148, 181, 189, 195 221, 231
Physics as a preparation for higher learning, 16, 19, 26, 29, 73, 84, 93, 107, 111, 134, 135, 141, 157, 164, 166, 191, 198, 239
Problem solving, 176, 215
Radio, 77, 97
Regression equation, 36, 46
Resourcefulness, 10, 14
Rotation system, 62
Rote learning, 187, 216
Scales or score cards, 90, 91, 113, 114, 177, 199
Science, instruction, 11, 16; rooms, 46, 61, 151, 179; sequences, 90, 103, 104, 110, 113, 127, 128, 134, 139, 159, 164, 175
Scientific interests, 49, 64
Sex differences, 52, 67, 117, 120, 141, 145
Shortened class period, 61, 77
Social value, 205, 206, 245, 246
Status of science teaching, 32, 33, 36, 42, 43, 46
Students, errors of, 40, 50, 158, 173; responses of, 6, 8; superior, 4, 5
Study outlines, 41, 51
Success, 37, 47, 81, 90, 103, 113, 137, 145, 170
Teaching, loads, 92, 115, 136, 139, 160; success, 109, 125, 126, 133; technics, 114, 121, 138, 144, 181; values, 114, 138
Tests, 5, 7, 17, 27, 34, 35, 44, 45, 55, 64, 70, 81, 170, 180, 196, 207
Textbooks, 18, 28, 95, 118, 171, 180, 199, 207
Time, 12, 17, 61, 77, 199, 240
Trends in science teaching, 45, 59, 114, 126, 138, 148, 150, 152, 177, 180, 201, 222, 242, 264
Units, 12, 17, 108, 132
Visual aids, 2, 129, 153, 182
Vocabulary, 43, 50, 54, 65, 69, 88, 174, 203, 214, 255
Work sheets, 24, 34, 112, 136

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The Physics Examination of the College Entrance Examination Board

THE August, 1940, issue of the AMERICAN JOURNAL OF PHYSICS contained the physics syllabus proposed by the College Entrance Examination Board's Commission on Examinations in Physics and Chemistry, and suggestions and criticisms were invited. The membership of the Commission follows:

Dean John T. Tate, University of Minnesota (Chairman)
Doctor Otis E. Alley, High School, Winchester, Massachusetts
Dean Janet H. Clark, University of Rochester
Doctor Curtiss S. Hitchcock, Lawrenceville School, Lawrenceville, New Jersey
Mr. John C. Hogg, Phillips Exeter Academy, Exeter, New Hampshire
Professor Erwin B. Kelsey, Yale University
Mr. Alfred R. Lincoln, Technical High School, Springfield, Massachusetts
Professor Duane Roller, Hunter College
Professor Francis W. Sears, Massachusetts Institute of Technology
Professor Mary L. Sherrill, Mount Holyoke College
Mr. Howard A. Taber, Hotchkiss School, Lakeville, Connecticut

The suggestions received were given careful consideration and many of them have been incorporated in the following syllabus, which has been adopted as the basis for the physics examinations to be set by the College Entrance Examination Board in 1942 and thereafter. Teachers will note, however, that the main topics remain unaltered.

The following redefinition of the requirement in physics indicates the nature and extent of the basic preparation considered necessary for college work. It is estimated that from two-thirds to four-fifths of the school year will be required to cover the basic topics suggested in the minimum syllabus given in Part I. Candidates will be examined on the minimum syllabus only.

Part II is intended to show how the basic material of Part I can be amplified. Additional specific material designed to meet the needs of the community and adapted to the level of the student body should also serve to enrich the basic course. Questions on topics in this suggested area will not be included, since it is felt that the science will be more effectively taught if the instructor is given greater latitude in the selection of topics.

In order that the objectives of the course of study may be fully realized, it is essential that the study of physics be accompanied by individual laboratory work as well as by class demonstrations. The laboratory work should occupy approximately one-third of the time devoted to physics and it should continue throughout the whole course. A list of experiments is not submitted, as it is believed that the experiments will need to be varied according to the facilities of a particular institution. It is assumed, however, that the student will have some laboratory experience with well-established experiments on fundamental laws. The arrangement of the syllabus does not imply a teaching sequence.

Part I

It is assumed that the student is familiar with the geometric relations connecting length, area and volume, and with the common English and metric units of these quantities.

Quantitative use of all physical laws is expected unless otherwise stated.

MECHANICS

Basic concepts

Weight
  Units: pound; gram
Force: generalization of weight concept
  Units: pound; gram
  Hooke's law: relation between force and extension or compression; measurement of force and weight by spring balance
Weight per unit volume, or weight-density; measurement by direct method
  Units: pound per cubic foot; gram per cubic centimeter
Specific gravity
Pressure: force per unit area
  Units: pound per square inch; gram per square centimeter

Fluids at rest
- Pressure in a liquid
  - Pressure at a point: the pressure is the same at all points at any given depth, and is the same in all directions at any given point
  - Force at a boundary surface: the force is perpendicular to the surface
  - Variation of pressure with depth: the pressure equals the product of the weight-density and the depth
  - Force on plane boundary surfaces: the force equals the product of the average pressure and the area
  - Pascal's law
  - Archimedes' principle
    - Submerged and floating bodies
    - Measurement of specific gravities of liquids, and of solids denser than water
  - Atmospheric pressure
    - Explanation: due to weight of air
    - Standard atmospheric pressure and its value in pounds per square inch
    - Measurement of atmospheric pressure by mercurial barometer; vertical height of barometric column in inches and in centimeters of mercury
  - Boyle's law
    - Qualitative explanation by kinetic theory

Work, power, and machines
- Concept of work
  - Units: foot pound, gram centimeter
  - Derivation of the principle of work (derivation based on some machine such as a lever or an inclined plane)
- Machines
  - Lever, wheel and axle, pulley and inclined plane
  - Ideal mechanical advantage
  - Torque, or moment of force
  - Center of gravity
- Friction and work against friction
  - (Coefficient of friction not required)
  - Actual mechanical advantage
  - Efficiency
- Power: time-rate of doing work
  - Units: foot pound per second; gram centimeter per second; horsepower

Force and motion
- Force as a vector quantity, that is, one which has both magnitude and direction
  - Graphical representation of forces
  - Vector addition (composition) of two forces by the parallelogram method
  - Components of a force, graphical method
    - Rectangular components, graphical and numerical methods
  - Equilibrium of forces
- Motion in a straight line
  - Constant velocity
    - Units: foot per second; centimeter per second; mile per hour
  - Average velocity
  - Instantaneous velocity
  - Constant acceleration
    - Units: foot per second, per second; centimeter per second, per second
  - Acceleration due to gravity
  - Newton's law of universal gravitation: the force of gravitational attraction between the two bodies is proportional to the product of their masses and inversely proportional to the square of their separation
- Newton's three laws of motion
  - Concept of mass, or of inertia
  - Relation of acceleration, force and mass: the acceleration is proportional to the force and inversely proportional to the mass

Energy
- Potential energy: energy of position or form
  - Potential energy of a raised weight in foot pounds and in gram centimeters
- Kinetic energy: energy of motion; kinetic energy is proportional to the mass and to the square of the velocity
- Conservation of energy; transfer and transformation of energy
- Kinetic-molecular conception of matter
  - Qualitative evidence: diffusion, gas pressure, heat conduction

Temperature and Heat

Temperature and its effects
- Measurement of temperature by liquid-in-glass thermometer
- Temperature scales
  - Fixed points and the division of the interval between them into degrees
  - Fahrenheit, centigrade and Kelvin (centigrade absolute) scales
- Expansion
  - Coefficient of linear expansion
  - Volume expansion of solids and liquids (qualitative)
  - Anomalous expansion of water
  - Expansion of gases
    - Qualitative explanation by kinetic theory
    - $P_1V_1/T_1 = P_2V_2/T_2$, or
      $P_1V_1/(t_1+273) = P_2V_2/(t_2+273)$

Quantity of heat
- Units: calory; British thermal unit
- Specific heat
  - Measurement of specific heat by simple calorimeter
- Heat as a form of energy
  - Mechanical equivalent of heat
- Changes in state
  - Fusion and solidification; heat of fusion and its measurement
    - Expansion of water on freezing
  - Vaporization and condensation; qualitative explanation by kinetic theory; heat of vaporization and its measurement
  - Boiling and evaporation
- Transfer of heat (qualitative)
  - Conduction and convection; radiation

Sound

Waves as carriers of energy
Examples of sources of sound waves
Longitudinal nature of sound waves
Speed of sound in air (approximate value)
Relation between speed, wave-length and frequency
Pitch, loudness and quality

Light

Transverse nature of light waves
Speed of light in a vacuum and in transparent materials
Refractive index as a ratio of speeds
Propagation of light in a homogeneous medium: the light travels in straight lines; rays and beams
Relation between speed, wave-length and frequency
Regular and diffuse reflection
Law of regular reflection
Refraction
Qualitative explanation of refraction and dispersion by the wave theory
Law of refraction (qualitative); total internal reflection and critical angle
Refraction and dispersion by a prism
Types of spectra in visible region
Wave-length and color
Image formation, ray treatment
Distinction between real and virtual images
Image formation by a plane mirror
Image formation by a converging lens; focal points and focal length of a lens; relation between object and image distances; relative size of object and image; application to camera and projection lantern

Magnetism and Electricity

Magnetism
Magnetic and nonmagnetic substances
Magnetic poles: like poles repel, unlike poles attract
Magnetic fields
Mapping by lines of force
General nature of the earth's magnetic field
Magnetization
Ewing theory of molecular magnets
Electric charges at rest
Electric charge: like charges repel, unlike charges attract
Electrons
Electrification by contact ("by friction")
Induced charges
Leaf electroscope; response when charged and uncharged
Conductors and insulators
Charges in motion
Current: time-rate of flow of electric charge
Effects produced by a current: electrolytic (simple chemical changes), heating and magnetic effects
Unit: ampere
Measurement of current by galvanometer or ammeter
Electromotive force and potential difference
Unit: volt
Measurement by voltmeter
Primary and secondary cells as energy converters
Resistance
Unit: ohm
Ohm's law
Measurement of resistance by voltmeter-ammeter method
Resistors connected in series and in parallel
Magnetic effects of a current
Relation between the direction of the current and the direction of the lines of force around a straight wire and around a coil
Electromagnets
Galvanometer
Simple direct-current motor
Chemical effects of a current
Electroplating: the metal is deposited on the cathode; the electrolyte is a salt of the metal
Heating effects of a current: the time-rate of heating (watts) equals the product of the resistance (ohms) and the square of the current (amperes^2)
Power and energy
Units of power: watt, kilowatt
Relation between horsepower and kilowatt
Units of energy: watt second (joule); kilowatt hour
Relation between watt second (joule) and calory
Computation of power: *power in watts = volts × amperes*
Electromagnetic induction
Lenz's law
Simple two-pole alternating and direct-current generator
The transformer

Part II—Extension

The following topics are strongly recommended as subject matter desirable for the enrichment of a well-balanced course, but questions on these topics will not appear in the examination.

Mechanics

Newton's second law of motion in the form $F = ma$; momentum; dyne and erg; coefficient of friction; motion with constant acceleration when initial or final velocity is not zero; projectile motion; centripetal and centrifugal forces.

Heat

Refrigeration; humidity and dew point; vapor pressure; effect of pressure on boiling temperature; heat of combustion.

Magnetism and Electricity

Coulomb law for electric charges; electric and magnetic field strengths; internal resistance and terminal potential difference of cells and generators; back electromotive force; conversion of galvanometer to ammeter and voltmeter.

Light

Snell law of refraction; telescopes and microscopes; the eye and spectacles; spherical and chromatic aberrations;

intensity of point source; illumination by point source; interference; plane polarized light; additive and subtractive color mixtures.

SOUND

Reflection of sound waves; measurement of speed of sound by resonance; vibrating strings and air columns; interference; beats.

MOLECULAR AND ATOMIC PHYSICS

Approximate size of molecules, Brownian movement; Rutherford-Bohr atom, electron, positron, proton, neutron, charge of electron; ionization, conduction in gases; emission of radiation by atoms and molecules; spectrum analysis; photoelectric effect, thermionic emission; x-rays; natural and induced radioactivity; the cyclotron, the Van de Graaff generator.

Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

18. Frescos in the *Tribuna di Galileo*, Part II

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THE four frescos in the lunettes above the walls of the vestibule and central hall of the *Tribuna di Galileo*[1] also merit reproduction and further description.

The first of these to meet the eye of the visitor as he enters the vestibule is reproduced in Plate 1. It shows LEONARDO DA VINCI and FRA LUCA PACIOLO, the mathematician, explaining LEONARDO's mechanical inventions to LODOVICO SFORZA, Duke of Milan—inventions in military and civil architecture, ballistics, hydraulics, and so forth, which were the supreme products of the mechanics of the sixteenth century. Artfully grouped around LODOVICO are various personages important in the history of the time—BRAMANTE, the ACCOLTI, GIULIANO DA SANGALLO, and others—all intently listening to LEONARDO's words.

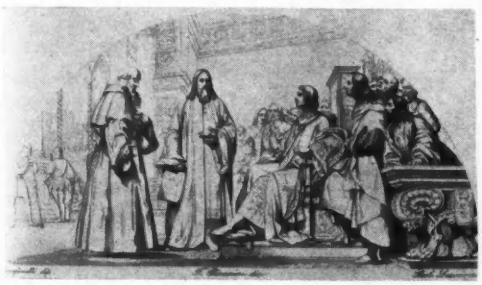

PLATE 1. LEONARDO DA VINCI EXPLAINING HIS MECHANICAL INVENTIONS TO THE DUKE OF MILAN.

[1] See reproductions 16 and 17 of this series.

In the opposite lunette, over the entrance to the vestibule and the last to meet the visitor's eye as he leaves the shrine, is the fresco reproduced in Plate 2. It portrays, and as far as possible with actual portraits of the persons who attended, the meeting of the Institute of France at which VOLTA expounded his experiments with the electric pile—experiments that opened a new field of research whose fuller exploration and theoretical interpretation were to become the greatest achievements of nineteenth-century physics. The variety of feelings expressed in the faces of those who witness the experiments is most striking. NAPOLEON, seated near VOLTA, in an attitude of profound attention fixes his keen eyes upon the immediate results of the experiments. The actions and expressions of MONGE, of BERTHOLLET, of VAUQUELIN are varied. DE FOURCROY shows his wonder; LACÉPÈDE shows wonder to an even greater degree, as might be expected of one whose own studies were in other fields. LAPLACE is dignified, LEGENDRE and DE MORVEAU are attentive, CUVIER is both benevolent and attentive, while BIOT shows by his expression and actions that he is preparing to criticize. In the midst of the display of all these different sentiments, VOLTA turns toward NAPOLEON, modestly, but also with confidence that the experiments will succeed.

These two compositions are the work of NICCOLA CIANFANELLI and represent probably his best work.

PLATE 2. VOLTA DEMONSTRATING HIS ELECTRIC PILE BEFORE THE INSTITUTE OF FRANCE.

The corresponding frescos in the central hall are reproduced in Plates 3 and 4. The first of these shows GALILEO in Pisa proving the laws of falling bodies by experiments on an inclined plane. It is the work of GIUSEPPE BEZZUOLI and succeeds in a remarkable way in contrasting the tranquillity of the young GALILEO with the anger, malevolence and envy of his enemies. In the center of the picture one sees an inclined plane down which a ball is rolling, while GALILEO,

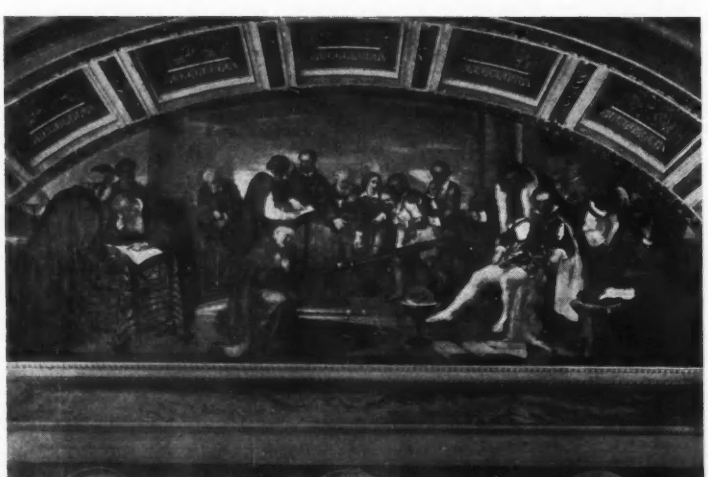

PLATE 3. GALILEO PROVING THE LAWS OF FALLING BODIES BY EXPERIMENTS ON AN INCLINED PLANE.

PLATE 4. THE ACCADEMIA DEL CIMENTO EXPERIMENTING ON THE REFLECTION OF COLD.

standing by, is explaining to MAZZONI the consequences which are to be deduced from the experiment. At the lower end of the incline a kneeling Peripatetic Friar is timing the descent of the ball by means of his own pulse beat and showing by his facial expression more of incredulity to contradict than of attention to judge; at the upper end is a perforated water jar, the sort of timepiece actually used by GALILEO. A group of four professors, to the left of the spectator, are anxiously searching for some passage in ARISTOTLE to disprove GALILEO's argument. An old man leaning on a staff shows uncertainty and curiosity, while the hand of a young disciple pointing to the ball seems to applaud the success of the experiment. The man to the left of GALILEO, in a great state of agitation, seems to be saying to himself, "If such things are true, whatever will become of our science?" And to the right of the spectator, sitting apart from the crowd with a scornful air and not deigning to pay attention to the experiment, is GALILEO's jealous opponent and would-be rival in mechanical science, DON GIOVANNI DE' MEDICI, who was soon to be successful in forcing GALILEO to resign his professorship. In the background are the Baptistery, the Cathedral and the Leaning Tower.

Plate 4 shows members of the Accademia del Cimento[2] carrying out their famous experiment on the apparent reflection of cold by a parabolic mirror. A block of ice is used as the source of cold, and this "cold" is reflected by a mirror toward a thermometer placed at its focus. VIVIANI and BORELLI are directing the experiment, which has already begun. BORELLI covers the mirror with a cloth while two other members observe the effect on the thermometer. The GRAND DUKE FERDINANDO II, seated near the table on which the experiment is being performed, indicates by means of the raised fingers of his left hand that he is taking part, while his brother PRINCE LEOPOLDO has arisen to observe the effect more closely. Behind him MAGALOTTI, the Secretary, is also observing very carefully in order to note the result in the diary. On the wall of the apartment is a bust of GALILEO. The whole composition is an exceedingly pleasing one and does great credit to GASPERO MARTELLINI, its creator.

[2] The ten members of the Academy (in addition to its two actively participating patrons, the Grand Duke Ferdinando II and his brother Leopoldo de' Medici) were Vincenzo Viviani, Alfonso Borelli, Francesco Redi, Carlo Dati, Carlo Rinadini, Alessandro Marsili, Lorenzo Magalotti, Antonio Oliva, and the two brothers, Paolo and Candido del Buono. For interesting accounts of the Academy's history, personnel and work see A. Wolf's *A history of science, technology, and philosophy in the 16th and 17th centuries* (Allen and Unwin, 1935), pp. 54–59, 87, 307, and M. Ornstein's *The role of scientific societies in the seventeenth century* (Univ. of Chicago Press, 1938), pp. 73–90.

A Demonstration of Some Critical Phenomena

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MANY industrial operations are carried out under conditions that are in the neighborhood of the critical state of the fluid in question. For this reason an understanding of the physical nature and phase behavior of fluids in close proximity to this state is desirable from an industrial as well as an academic standpoint. An understanding of such phenomena is of special importance in the petroleum industry. Conditions in many underground reservoirs and certain refinery operations are such that the properties of gas and liquid phases in the neighborhood of the critical state are of practical importance, and rather extensive experimental programs have been undertaken to establish the behavior of these fluids. For these reasons it was considered worth while to develop demonstration equipment that would permit the visualization of the critical behavior of a one-component system.

For the most part, critical phenomena have been demonstrated by the use of small glass capsules containing a fixed quantity of the substance whose behavior is to be depicted. With equipment of this kind it is possible only to follow the course of events resulting from a change in temperature at one particular specific volume, which is usually chosen so as to be approximately equal to the specific volume at the critical state. In connection with the study of the volumetric and phase behavior of organic substances, Young and co-workers[1] developed an apparatus involving a glass capillary tube which permitted variation in the volume and temperature of the sample, the measurement of the resulting equilibrium pressure and the observation of the system in question. This type of apparatus has been utilized in many subsequent studies[2,3] of systems in the neighborhood of the critical state. Experience of the writers with this type of equipment indicated the possibility of utilizing such equipment in connection with lecture demonstrations. However, it is possible for this purpose to dispense with many of the refinements employed in the apparatus designed for quantitative studies.

A schematic drawing of the arrangement of the essential parts of the demonstration apparatus is presented in Fig. 1. It consists of a capillary tube *A* closed at one end, in which the fluid is confined over mercury. The capillary tube is connected through a packing gland *E* to a steel vessel containing a plunger *B*. This part of the apparatus is filled with mercury and is so arranged that the volume of the system may be varied over reasonable limits by movement of the plunger *B*. A Bourdon tube pressure gauge *C* which is filled with oil is connected to the mercury-filled portion of the apparatus through an oil-mercury interface in the small chamber *D*. For the demonstration of the critical behavior of the paraffin hydrocarbons, the pressure gauge *C* should have a working range up to approximately 1000 lb/in.^{2}. The plunger assembly *B* may be satisfactorily prepared from a small, forged steel needle valve if the conventional packing is replaced by a series of alternate rings of soft leather and Neoprene. The details of the packing gland *E* utilized to connect the capillary to the steel parts of the system are indicated in a part of Fig. 1. The Pyrex capillary tube employed by the writers has an inside diameter of 0.059 in. and was carefully annealed at a temperature of 970°F to remove internal strains which often cause

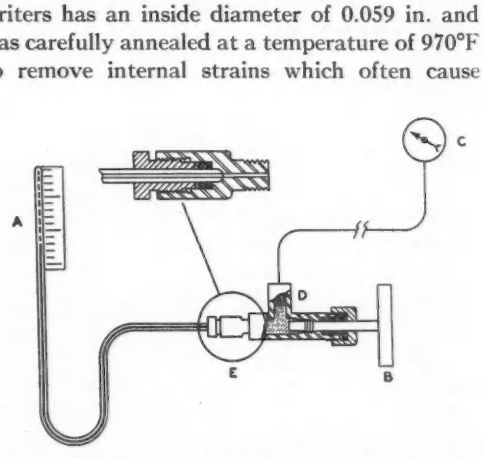

FIG. 1. Diagram of the essential parts of the apparatus.

[1] Rose-Innes and Young, Phil. Mag. [5] **47**, 353 (1899).
[2] Kay, Ind. Eng. Chem. **28**, 1014 (1936).
[3] Nysewander, Sage, and Lacey, Ind. Eng. Chem. **32**, 118 (1940).

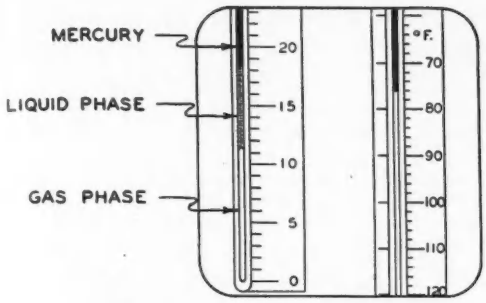

FIG. 2. Appearance of capillary and projection thermometer on screen.

failure of glass capillaries at a relatively low pressure.

It is necessary to employ a rather pure material in order to avoid difficulties in the demonstration of the critical behavior. The material utilized should be carefully de-aerated by refluxing in a fractionation column at reduced pressure. It then may be distilled into the capillary tube, employing conventional high vacuum technic. The material, after being distilled into the capillary, is frozen by immersion in liquid air. The remaining parts of the capillary are filled with mercury with the exception of a space adjacent to the sample approximately equal to its volume, which must be provided for the expansion resulting from an increase in temperature. The mercury in the lower part of the U-tube is then frozen with liquid air or solid carbon dioxide and maintained in this condition until the capillary is attached to the mercury-filled steel parts of the apparatus by means of the packing gland *E*. Reasonable care in this operation is necessary to avoid trapping of small quantities of air in the end of the capillary which may vitiate the sample employed. After attachment of the capillary, the equipment is ready for use as soon as it is immersed in a bath of controlled temperature.

For demonstration purposes, the writers have employed a projection lantern with an aqueous solution of copper sulfate for an absorption screen in front of the capillary tube. An air blast from an electric heater directed against the capillary tube and a projection thermometer afford satisfactory means of controlling and measuring the temperature. Manual control of the electric energy input to the heater suffices for most purposes. However, it is somewhat difficult to follow isothermal changes in state in the immediate vicinity of the critical state where small variations in temperature markedly influence the properties of the system.

Figure 2 shows the appearance of the capillary and the projection thermometer on the screen. A small glass scale is mounted alongside the capillary in order to indicate semiquantitatively the total volume of the system. The inverted image does not appear to cause difficulty in the demonstration of the phenomena. However, this inversion may be eliminated if desired by suitable modification of the optical system. The pressure gauge may be projected from a second lantern using either transmitted or reflected illumination. In the former case it is necessary to dismantle the Bourdon type gauge and prepare a glass scale to permit quantitative indication of pressure. If reflected illumination is employed, the gauge may be utilized in the assembled condition provided the glass face is removed.

A volume-temperature diagram for ethane[4] is depicted in Fig. 3 for the region in the neighborhood of the critical state. Ethane is a satisfactory material to employ for demonstrations of this nature since[5] it exhibits a critical temperature of

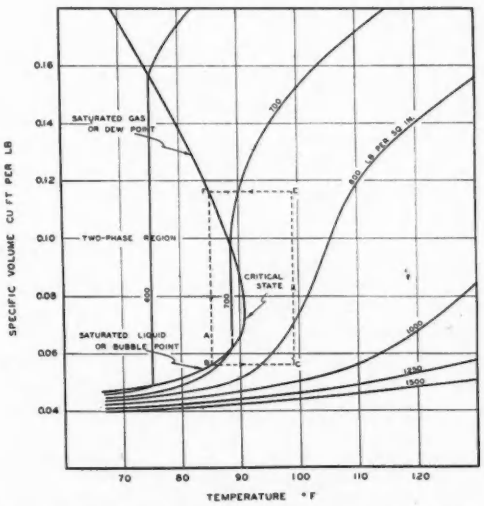

FIG. 3. Specific volume-temperature diagram for ethane.

[4] Sage, Webster, and Lacey, Ind. Eng. Chem. **29**, 658 (1937).
[5] Int. Crit. Tab., vol. 3, p. 248.

89.8°F and a critical pressure of about 717 lb/in.^{2} However, the purification of this material requires suitable fractionation equipment, and it is possible that carbon dioxide with a somewhat higher critical pressure would be simpler to employ in some instances.

Equipment of this kind permits the traversing of isobaric, isothermal or isochoric paths throughout all parts of the critical region within the pressure and temperature limitations of the apparatus. For example, it is interesting to follow a path without change in phase from saturated liquid to saturated gas. This may be accomplished in the following fashion. From a state in the two-phase region at A in Fig. 3, saturated liquid—that is, bubble point—may be reached by an isothermal compression. This process is followed by an isochoric increase in temperature to a value above the critical temperature, such as point C. The fluid may then traverse the isothermal path in the single-phase region to E by appropriate change in the effective volume of the capillary. The temperature then may be reduced under isochoric conditions to saturated gas—that is, dew point—at F, and the original state in the two-phase region may be regained by an isothermal expansion. This sequence of states illustrates the continuity of phase in the case of a pure substance above the critical temperature. The apparatus is also convenient for illustrating the variation in the relative volume of the phases upon increase in temperature at specific volumes larger and smaller than the critical value. Furthermore, the phenomena of opalescence and of adiabatic cooling upon rapid expansion may be followed in detail.

Experience with this equipment has indicated that for demonstration purposes it is unnecessary to employ mechanical agitation within the capillary. However, if it is desired to demonstrate critical phenomena for binary or multicomponent mixtures, the use of mechanical agitation is essential. This may be provided by the insertion of a small steel ball in the capillary. This ball may be oscillated by the use of an electromagnet mounted to move coaxially with the capillary. Furthermore, observation of variations in the rate of fall of the steel ball in the tube clearly indicates the rapid change in the viscosity of the gas and the liquid phases as the critical state is approached. The hazards involved in the use of this equipment are negligible, since the quantity of fluid enclosed in the capillary is small enough that the energy available upon failure of the glass is insufficient to cause damage even to adjacent pieces of equipment.

NOTES AND DISCUSSION

Moment of Inertia Experiments

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TWO methods of measuring moment of inertia are used as quantitative demonstration experiments in our freshman physics course. In the first, a pendulum consisting of a large cast-iron wheel is suspended on a knife edge from a series of five holes drilled in its spokes, and the period of vibration for each axis of suspension is measured with a stop watch. Then, since $T=2\pi\sqrt{(I/Mgh)}$, where I is the moment of inertia about the axis of suspension and h is the distance from the axis to the center of mass, and since $I=MK^2+Mh^2$, where K is the radius of gyration, we can write: $h^2=(g/4\pi^2)hT^2-K^2$. This is in the form $y=mx+b$. When the values of hT^2 are plotted as a function of h^2, the points fall on a straight line whose slope, when multiplied by $4\pi^2$ gives the value of g and whose y intercept gives the radius of gyration squared. The possible novelty of the demonstration lies in the use of the graphical solution. The wheel has a diameter of 52 cm and weighs 16.64 kg. The holes are 22.3, 18.5, 14.9, 11.2, and 8.2 cm from the center of mass.

The second experiment is well known. A metal disk rolls on an axle down two parallel metal bars forming an inclined plane. The dimensions and mass of the disk and the time required to travel a known distance down the plane are measured, and the moment of inertia is calculated by three different methods.

Several Simple Demonstrations

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1. The well-known demonstration of the resonant response of a tuning fork[1] can be modified to advantage in the following manner. The responding fork, mounted on its resonance box, is set on the lecture table. A simple pendulum consisting of a thread and a small steel sphere, marble or ivory ball is supported so that the bob *just touches* the outside, upper edge of the tuning fork. When another mounted tuning fork is removed some distance, struck and then silenced, the pendulum bob will be set into motion. If the length and contact of the pendulum

are properly adjusted, the amplitude will be surprisingly large. The effect is, in fact, a little "spooky."

2. The process of osmosis is usually shown with a carrot or with a membrane sealed over the end of a thistle tube. However, ordinary Cellophane, such as is found around cigarette packages, performs beautifully as a permeable membrane.

3. In discussing density and the Archimedes principle, I have found the following simple demonstrations popular and instructive: (a) pass around the class a pint bottle of mercury and a pint bottle of water; it is an experience that few forget; (b) fill a stout shallow dish with mercury and drop a large steel ball-bearing into the mercury from a height of approximately 6 in.; the buoyant effect is spectacular.

[1] Sutton, ed., *Demonstration experiments in physics*, S-115, p. 181.

Demonstrating the Doppler Effect

C. W. Heaps
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THE modern college student, in these days of high speed automobiles and musical horns, has usually had some experience with the Doppler effect before he meets the description of the phenomenon in his physics textbook. Although the demonstrations in the lecture room are likely to be less direct than those of the open road, they nevertheless have a definite value. Professor John Zeleny has described[1] a lecture demonstration which is sometimes used but is not, in fact, direct and unambiguous. A large tuning fork of high pitch is moved toward a reflecting wall or away from it; the resulting beats are supposed to demonstrate the difference of wave-lengths of the direct and reflected waves.

It appears that no change of wave-length is necessary in order that beats be produced in this demonstration. Suppose that a stationary fork is held at the proper position in front of a wall, with observers located along the normal to the wall through the fork but outside the fork. Then it is possible for the reflected wave train to interfere destructively with the direct wave train so as to produce a sound minimum for all the observers. For a different position of the fork there may be a sound maximum. Motion of the fork along the normal causes maxima and minima of sound to occur successively, thus producing a beating effect similar to that which would be caused by a Doppler change of pitch.

Suppose that the fork is stationed at a distance y in front of the wall. Let x be the distance from the fork to the observer, and let x and y be in the same straight line. Neglect damping and assume perfect reflection. For the sake of simplicity consider that the fork sends out two trains of plane waves along x and y, the phases agreeing at the source. One of the waves suffers a phase change at reflection.

The displacement of the air at the observer will be the sum of the displacements a_1 and a_2, respectively, of the direct and reflected waves. These displacements may be represented in the usual way by $a_1=a_0\cos\omega(t-x/v)$ and $a_2=-a_0\cos\omega\{t-(x+2y)/v\}$, where a_0 is the amplitude of the fork vibration, ω is $2\pi\nu$, ν is the frequency, t is the time and v is the speed of sound. The resultant displacement, $a=a_1+a_2$, turns out to be

$$a=a_0\{(\cos\alpha-\cos\beta)\cos\omega t+(\sin\alpha-\sin\beta)\sin\omega t\}, \quad (1)$$

where $\alpha=\omega x/v$ and $\beta=\omega(x+2y)/v$. Equation (1) may be written in the form

$$a=F\cos\phi\cos\omega t+F\sin\phi\sin\omega t=F\cos(\omega t-\phi), \quad (2)$$

where $\tan\phi=(\sin\alpha-\sin\beta)/(\cos\alpha-\cos\beta)$ and $F^2=2a^2_0\times(1-\cos 2\omega y/v)$.

The sound intensity at the observer is proportional to F^2, hence this sound intensity will have minimum value when F^2 is a minimum, that is, when $\cos 2\omega y/v=1$, or when $2\omega y/v=2n\pi$, where $n=0, 1, 2, \cdots$. Similarly the sound is a maximum for $2\omega y/v=(2n+1)\pi$. We thus get sound minima when $y=nv/2\nu$ and sound maxima when $y=(2n+1)v/4\nu$.

The distance D between two successive positions of the fork which result in sound minima at the observer is $v/2\nu$. It is quite easy to verify this relation with a tuning fork of frequency 2048 vib/sec. The fork is held stationary at the positions giving sound minima (or maxima) while distances are being measured, so that any Doppler effect is eliminated.

Suppose that the fork is moving with speed V toward the wall. Then, independently of any Doppler effect, the observer will hear V/D beats per second, and $V/D=2\nu V/v$.

We now consider the moving fork in relation to the Doppler effect. The approximate equation for the Doppler effect gives for the frequencies of the direct and reflected waves, respectively, $\nu_1=\nu(1-V/v)$ and $\nu_2=\nu(1+V/v)$. These two tones give a beat frequency $\nu_2-\nu_1=2\nu V/v$, which is the same as the frequency of beats observed, as previously explained, when there is no Doppler effect. The beats caused by the Doppler effect are superposed on those that would exist if there were no change of wave-length, and the two phenomena cannot be distinguished experimentally. This demonstration is, therefore, not perfectly clear and unambiguous.

In the usual demonstration, first described by Mach[2] in 1861, pitch changes are produced by whirling a sounding source in a circle. It is true, as Professor Zeleny[1] has pointed out, that many students are deficient in perception of pitch changes, so the experiment may not be effective. The method of König[3] is not subject to this objection. Here two stationary tuning forks on resonance boxes produce about four beats per second when sounded simultaneously. One of the forks, say, the slower one, is then moved back and forth over as long a range as possible in front of the class. The number of beats per second decreases when the fork approaches the class and increases when it recedes. In this demonstration, as well as in that of Mach, it is well to minimize reflections from near-by walls.

[1] J. Zeleny, Am. J. Phys. **9**, 173 (1941).
[2] E. Mach, Ann. d. Physik **112**, 66 (1861).
[3] R. König, *Quelques experiences d'acoustique* (Paris, 1882), p. 41.

A Simplified Direct-Reading Potentiometer

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IT is quite common to find that students in college physics courses beyond the first course have difficulty in grasping the principle of the direct-reading dial-type potentiometer. This difficulty is due in part to the difference in design between the simple board-mounted slide-wire potentiometer commonly used in the elementary laboratory and the more compact direct-reading dial-type potentiometer, and in part to a failure to understand the principle of the direct-reading potentiometer. The present potentiometer is designed to minimize both these difficulties; it bridges the gap between the slide-wire and dial types and makes it possible to teach the principle of the direct-reading potentiometer with very simple apparatus.

In principle the instrument follows the design of the Leeds and Northrup Students' Potentiometer. In Figs. 1 and 2 the corresponding parts are lettered alike. The essential part of the apparatus P is a 200-ohm 10-in. standard screw-drive rheostat-potentiometer having a resistance winding of length nearly 20 cm. The scale S for reading the emf directly consists of a student-type K. and E. slide rule with the "sliding" scale glued firmly in place and with a paper scale graduated in millimeters (with centimeter marks numbered) pasted to the top surface of the slide rule. This paper metric scale is attached so that the mark "0 cm" appears vertically over the left-hand end of the resistance winding of P. The slide rule index I is permanently fastened to the screw-driven sliding contact of P so that the position of I can be adjusted readily at the knob K. A pair of General Radio rheostats of resistance 200 and 2500 ohms, respectively, provides the "external" resistance R used in balancing the potentiometer against a standard cell.

In use, I is adjusted along S to the scale setting that corresponds numerically to the emf of the standard cell.

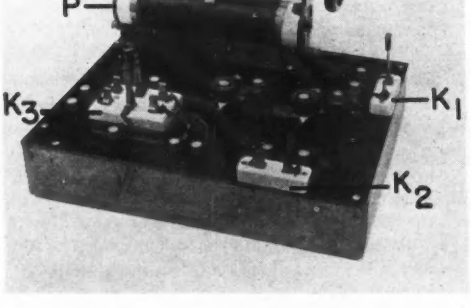

FIG. 1. Simplified direct-reading potentiometer.

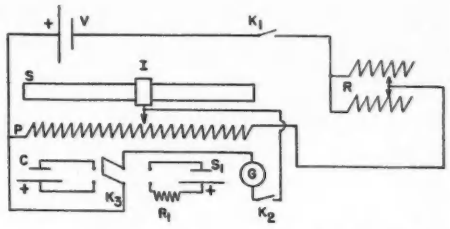

FIG. 2. Circuit of potentiometer and auxiliary apparatus for measuring electromotive force: S_1, standard cell with protective resistance R_1 in series; C, test cell; K_1, K_2, K_3, switches.

Since P has 200 ohms resistance for a length of 200 mm (approximately), 100 mm on S is called "1 volt" in order to give 1 volt potential drop in 100 ohms of P. Balance then is established by adjusting R until the deflection of the galvanometer G (Fig. 2) is zero.

The data in Table I were chosen at random from student reports to show how the simplified potentiometer compares with the Leeds and Northrup Students' Potentiometer for measurement of unknown electromotive forces. Note that the simplified potentiometer gives four-figure accuracy as against five for the L. and N. instrument.

TABLE I. *Typical data.*

	EDISON CELL (ABS. VOLTS)	BURGESS DRY CELL (ABS. VOLTS)
Simplified potentiometer	1.352	1.574
L. and N. Students' Potentiometer	1.3466	1.5686

Use of the simplified direct-reading potentiometer in the general physics course indicates that with it the principle of this type of instrument is learned easily. The simplified instrument aids also as an introduction to the precision direct-reading potentiometer in intermediate courses.

The Poundal

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IN his letter, "The poundal again,"[1] A. P. R. Wadlund admits that the poundal is not "used" but he implies that this is not sufficient reason for dropping it from physics courses. In particular he suggests that dynes are "not measured or even used" and therefore the same argument can be used for the elimination of the dyne. This is a totally unacceptable argument. The dyne is used. True, we measure forces and weights in grams, but the common units of energy and power in the metric system—erg, joule, watt, kilowatt—are all based on the dyne. Nothing that is commonly used depends on the poundal.

NOTES AND DISCUSSION

Off with its head I say. It is useless and adds to the difficulties that students have with a subject which is difficult enough without it.

[1] *Am. J. Phys.* **9**, 189 (1941).

An Undergraduate Program in Meteorology

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IT was ably pointed out by Professor Albright[1] that courses in physical meteorology should be offered more frequently by our colleges, and that the physics department should logically be the sponsor for these courses. This fact has been emphasized in the past year or so because of the great interest shown by the Federal government, by commercial airlines and by aspirants for civilian pilot's licenses in courses in aeronautic meteorology. The Civilian Pilot Training Program of the C.A.A. has considered the matter seriously, and hundreds of college students are taking the 24-hour course in the subject. The expanding field of meteorology is requiring more and more persons who have "majored" in the subject and taken advanced work in it at such institutions as the California Institute of Technology, the Massachusetts Institute of Technology, Pennsylvania State College, New York University, and the University of Chicago.

In response to a growing demand for undergraduate instruction in meteorology from students who are contemplating either graduate work in that subject or entrance into aeronautics, the University of Cincinnati, through the department of physics, of which Professor S. J. M. Allen is Chairman, has arranged the following curriculum, the pursuance of which will satisfy the requirements of the College of Liberal Arts throughout a regular four-year course leading to the bachelor's degree.

Freshman Year	*Junior Year*
English	Differential equations
General physics, with laboratory	Introduction to theoretical physics
Civilization or social science	Philosophy or psychology
Introductory German	Navigation
Mathematics (analytics)	Hydrodynamics
Physical education	Intermediate mechanics, with laboratory
Sophomore Year	*Senior Year*
English	Thermodynamics
Calculus	Synoptic meteorology
Scientific German	Dynamic meteorology
Elements of meteorology	Meteorology laboratory
Geography of North America	Vector analysis
Climatology	Descriptive astronomy
	Intermediate heat, with laboratory
	Readings in meteorology

The elective technical courses suggested are taken from the departments of physics, mathematics, geology, aeronautic engineering and astronomy. The new program goes into effect in September, 1941.

[1] J. G. Albright, Am. J. Phys. **8**, 282 (1940).

RECENT PUBLICATIONS AND TEACHING AIDS

PHILOSOPHY OF PHYSICS

Between Physics and Philosophy. PHILIPP FRANK, Visiting Lecturer, Harvard University. 238 p., 14×21 cm. *Harvard Univ. Press*, $2.75. Professor Frank, who was professor of theoretical physics at the German University in Prague from 1912 to 1938, has long been a distinguished contributor to the philosophy of physics. The present volume consists of English versions of essays that he has published in European periodicals from 1908 to 1938. The unifying theme is the elimination of metaphysical elements from science by the doctrines of Ernst Mach.

When the foundations of modern science were laid in the seventeenth century, physicists like Galileo and Newton assumed that the object of science is a real world independent of our experience of it. This presupposition is expressed in practically all textbooks by the distinction between objective physical processes and subjective perceptions. This bifurcation of nature into a real world and an apparent one, to borrow an expression from Whitehead, has been criticized by philosophers. In contrast to *realism* there was created the theory of *idealism* according to which reality is mental. During the last decades of the nineteenth century Mach attempted to purge science of metaphysics by the doctrine that the problem of science is the economical representation of connections between perceptions. He taught that an object is only a symbol for a complex of elements of sensation; atoms are fictions that ultimately will be eliminated from physics. This doctrine, usually called *phenomenalism* or *positivism*, has been a center of controversy in philosophy of science. Max Planck has been one of the most persistent critics of positivism, because he believes that acknowledgment of the nonexistence of an external world would weaken the creative impulse of scientists. Professor Frank, however, maintains that Mach's doctrine is independent of the metaphysical issue between realism and idealism, which he holds is illusory since it cannot be solved by experience. His interpretation of Mach is not that objects are held to be complexes of sensations, but that all propositions of science can be reduced to statements about perceptions. However, he concedes that Mach erred in not recognizing the permanent instrumental value of atomic theories.

Two essays in the volume are specifically devoted to the philosophy of Mach. In other essays the author shows that arguments for the metaphysical theory of idealism or spiritualism are not to be derived from the theories of relativity and quanta. A special essay is devoted to refutation of criticisms of the relativist concept of length. One on Bohr's concept of complementarity criticizes attempts to derive from it support for vitalism and the theory of free will. Probably the most constructive essay is the "The law of causality and experience." The law asserts that if, in the course of time, the state A of the universe is once followed by the state B, then whenever A occurs B will follow it. In

agreement with the conventionalism of Poincaré, Professor Frank interprets the law as a definition of *state*. If the law is not obeyed we assign to a system new state variables so that the law is obeyed.

Professor Frank's philosophy of physics may be expressed by the statement that the problem of physics is the construction of symbolic systems for the representation of connections between perceptions. His contribution is primarily expository and critical, for by definition the doctrine rules out speculations that transcend the realm of experience. Whether or not one accepts Professor Frank's standpoint, his analyses are always expert and enlightening. —V. F. LENZEN.

ADVANCED PHYSICS

Reports on Progress in Physics. Vol. VII. J. H. AWBERRY. Editor. 362 p., many figures, 18×25 cm. *The Physical Society* (London), $4.75, postpaid. (A limited number of copies is available at The American Institute of Physics, 175 Fifth Avenue, New York). In the present volume, as in the others of this well-known series, the contributors have been notably successful in achieving their main object—to help the physicist to keep himself informed of the advances constantly being made in those departments of physics in which he is not specialized. Moreover, they have supplied comprehensive bibliographies which should be of value to the specialists as well. The articles cover advances up to the middle of 1940 and are as follows: Sound, E. G. RICHARDSON; Musical acoustics, E. G. RICHARDSON; Photoelectric spectrophotometry and its use in industry, W. D. WRIGHT; Infra-red spectra of polyatomic molecules, HARALD H. NIELSEN; Gamma radiations emitted in nuclear processes, N. FEATHER; Bohr theory of nuclear reactions, R. PEIERLS; Electron microscopes of high magnification, O. KLEMPERER; New lens systems, H. W. LEE; Absorption of light in interstellar space, A. HUNTER; Solar physics, A. D. THACKERAY; Surface tension, R. C. BROWN; Equations of state, J. A. BEATTIE, W. H. STOCKMAYER; Electrical discharges in gases and their applications, V. J. FRANCIS, H. G. JENKINS; Interactions of gases with metals and crystalline solids, J. K. ROBERTS; Viscosity and the nature of substances of high molecular weight in solution, F. EIRICH; Development of the teaching of experimental physics in British universities, A. FERGUSON. Volumes III, V and VI of this useful series are also still available.—D. R.

PHOTOGRAPHY

Kodak Reference Handbook: Materials, Processes, Techniques. 521 p., many figures and tables, 18×23 cm. *Eastman Kodak Company* (Rochester, N. Y.), $2.75. This compilation of the contents of data books on films, papers, and so forth, published by the Eastman Kodak Company in recent years will be found indispensable as a reference in connection with photography courses in which Eastman products are used extensively. The material has been reorganized into ten sections as follows: lenses, films, filters, Kodachrome, papers, darkroom, development, formulas, copying, slides. The sections are tab indexed and each section contains a page and marginal index of the type employed in the *Kodak Data Book on Photographic Papers* and the other pamphlets of the same series. There is also an alphabetical index for the entire book. The 17-ring loose-leaf binder has a moisture-proof outer surface and is easily opened for the insertion of additional pages. The publishers intend to keep the handbook up to date by supplying supplementary pages of specifications as new products are marketed. The first supplement has already appeared as *Kodak Data Sheet Packet A* and sells for 15 cts.; it contains supplementary pages for five of the ten sections, and is in the form of a stapled pamphlet with the pages punched for insertion in the handbook either as a unit or, separately, in the appropriate sections. The pamphlets in the *Kodak Data Books* series from which the present reference handbook was compiled are still available for those who do not feel the need of the larger volume.—WILSON WOODCOCK.

PAMPHLETS AND CHARTS

Lecture Demonstrations with the Common Gases. 19 p., 5 fig., 10×19 cm. *The Matheson Co.* (East Rutherford, N. J.), gratis.

Revere Weights and Data Handbook. 33 p., 22×28 cm. *Revere Copper and Brass Inc.* (230 Park Avenue, New York), gratis. Useful conversion tables and data on copper, brass and bronze products.

Teaching Kit of Aviation Aids. *United Air Lines* (5959 S. Cicero Ave., Chicago), 10 cts. Intended for use in schools; includes a manual of teaching suggestions, 12 pictures, 11×13 in., of planes and air travel, aviation wall map, 20×24 in., and other similar material.

Timekeeping Through the Ages. Katherine S. Vandoren. LC600. *National Bureau of Standards*, Washington, gratis. Very elementary.

Edison Storage Batteries. 44 p., 65 fig., 22×28 cm. *Thomas A. Edison, Inc.* (Adv. Dept., West Orange, N. J.), gratis. A completely rewritten edition of a monograph on secondary battery instruction that was issued originally in 1916 at the invitation of the Joint Committee on Physics. The text has been brought up-to-date and much new material has been added, including a series of exercises on the characteristics and industrial applications of the nickel-iron-alkaline battery. The illustrations are excellent.

MOTION PICTURE FILMS

Geometry in Action. 16 mm, sound, 10 min. *Bald Eagle Film Productions* (New Haven, Conn.), rental. Geometry in everyday life.

Exploring with X-Rays. 16 or 35 mm, sound, 40 min. *General Electric Co.* (1 River Road, Schenectady, N. Y.), loaned gratis or sale. History, development and modern knowledge of x-rays.

Curves of Color. 16 mm, sound, in colors, 10 min. *General Electric Co.*, loaned gratis or sale. Difficulty of matching colors; necessity for describing colors accurately; operation of photoelectric spectrophotometer.

DIGEST OF PERIODICAL LITERATURE

Electric Bells and Spark Coils

Bells and spark coils. G. Ghey; *Sch. Sci. Rev.* **22**, 288–293 (1941). The self-sustained make-and-break contact has been dealt with both in principle[1] and in practice.[2] The parts played by self-induction and eddy currents in the operation of the ordinary door bell driven by direct current are easily overlooked; yet, without at least one of these phenomena, the bell would not work. With the aid of a cathode-ray oscillograph, a bell can be made to produce a closed curve analogous, but not strictly equivalent, to an engine indicator-diagram. The gong and clapper of the bell are removed and a small rectangular metal flag is substituted for the clapper. The image of a straight-filament lamp is focused on the flag, with one end extending over the edge. Behind the flag is a gas-filled photoelectric cell. As the flag vibrates with the armature, the light falling on the cell increases or decreases by an amount that is proportional to the distance moved by the armature. The output of the cell is amplified and applied to one pair of plates of the cathode-ray tube. The other pair of plates is made to give a deflection of the cathode beam that is proportional to the change of magnetic flux, by a method such as is used for drawing hysteresis curves.

If the time-constant L/R of the circuit is reduced by increasing the voltage applied to the magnet and at the same time inserting enough resistance to keep the maximum current the same as before, then the rate of rise of current and of flux is more rapid, the area enclosed by the diagram is less, and the armature vibrates less vigorously. Eddy currents in the solid iron core of the magnet and in the armature reduce the rate of change of flux, so that even with infinitesimal time-constant, the "indicator-diagram" will enclose a finite area. The effect of eddy currents can be increased by winding the coils on copper spools or by surrounding them with a secondary coil. Closing and opening the secondary circuit increases and decreases the loudness of a continuously ringing bell.

The time-constant of the circuit may be increased by adding inductance in series. A 6- or 8-v battery, a rheostat of about 100 ohms and a coil of from 500 to 1000 turns are connected in series with a bell. The rheostat is adjusted until the clapper of the bell, though vibrating, just fails to hit the gong. The insertion of a laminated iron core into the coil causes the bell to ring; as the core is removed, the sound dies away. In this circuit, although the average value of the current decreases when the core is inserted, so that there is less energy available, more energy is spent in friction, sound and losses in the core.

The possibility that a difference in phase between the armature and the elastic contact strip is a contributing factor to the operation of a bell is ruled out, since in ordinary bells this phase difference is negligible.

Similar considerations apply to a spark coil with electromagnetic make-and-break; but here, because the core is laminated, the effect of eddy currents is small. The effect of a condenser, connected in parallel with the contacts, in increasing the rate of fall of the flux, is well known. It is instructive to study a spark coil with a double-beam oscillograph, in which one beam draws a curve of primary current *versus* time, the other a simultaneous curve of secondary voltage *versus* time. The effect of the condenser can be made apparent from such curves.—J. D. E.

[1] N. C. Little, Am. J. Phys. (Am. Phys. T.) **4**, 139 (1936).
[2] W. C. Elmore, Am. J. Phys. **8**, 394 (1940).

Physical Terminology

Atomic weight unit. W. C. Sumpter; *J. Chem. Ed.* **18**, 246 (1941). Instead of coining a new word, such as "pel" or "crith," for the unit of atomic weight, we might well follow Brinkley's example and call the unit just what it is, *the atomic weight unit*. The definition of the unit as the mass that is $\frac{1}{16}$ that of an oxygen atom seems to offer less difficulty to beginners than does the presentation of atomic weights as ratio numbers based upon the value of 16 for oxygen.—D. R.

Color terminology. Anon; *J. Sci. Inst.* **18**, 118 (1941). A recent discussion of terminology arranged by the Physical Society (London) Color Group brought out the fact that confusion has arisen through the growth of independent terminologies for each trade. Moreover, the physicist's terminology is not always satisfactory owing to the frequent confusion between the objective and subjective attributes of color.

The usual terms employed by the physicist to describe the characteristics of a color are *brightness*, *hue* *saturation*. To the physicist and the photometrist, *brightness* means the same thing; but that meaning is different from what is generally meant by a "bright color" and certainly is different from what the dyer means when he uses such an expression. Brightness seems to be the most difficult attribute to describe in a generally acceptable manner. *Lightness* is preferred by some; a new term, "photolicity" was also suggested.

Hue has fewer critics, although the dominant hue is sometimes confused with the wave-length in the visible spectrum at which the energy is a maximum.

To some, *saturation* does not seem to describe adequately the characteristic it is supposed to represent, although to many it presents no difficulty; moreover, it is used in other fields of physics with a parallel significance. *Vividness* and *richness* were alternative suggestions. "Purity" as a term has little intrinsic significance. It was suggested that the description of saturation as the attribute that varies when a color is mixed with gray (when speaking in terms of pigments) is misleading, in that for dark colors the gray required will be near to black and it is difficult to decide how the saturation is then changed.

Strength is a term appropriately used by dyers to describe the attribute of a color associated with the concentration of a dye; unfortunately, a change in strength causes a change in both saturation and brightness. Thus confusion

arises not only because different terms are used for the same property or the same term for different properties, but also because there is not always a one-to-one correspondence between the variables used by different workers. The terms *shade* and *tint* are used somewhat loosely, each may have more than one meaning, and both are widely used in everyday language; all this renders them unsuitable as technical terms with precise definitions.—D. R.

Archimedes' Principle

Weighing living marine animals. H. A. F. Gohar; *Nature* **147**, 177 (1941). A living marine animal, weighed in the ordinary sea water of his habitat, has the apparent weight w when the specific gravity of the water is S. The volume of the animal, exclusive of internal cavities which are in communication with the exterior and contain sea water, is V. If the specific gravity is now altered by about 0.01 by the addition of sea salt or distilled water, the apparent weight corresponding to this new specific gravity S' is w'. From these data one can compute the weight W of the animal in air, exclusive of the water contained in its external cavities but in communication with the exterior. In practice, the weighing should be made both in water of larger and smaller density than normal sea water, and a sufficient time should intervene so that physical and chemical equilibrium will be obtained between the animal and its surroundings. Active and free-swimming animals must be enclosed in a perforated tube or netting, previously weighed in the water used.—J. M.

Check List of Periodical Literature

Applied x-rays. V. Hicks, B. E. Warren, C. S. Barrett, J. A. Bearden; *J. App. Phys.* **12**, 362–413 (1941). Five articles on x-ray physics, tubes, diffraction methods, determination of constitution diagrams, evaluation of N and e, and x-rays in medicine.

Applications of radioactive tracers to biology and medicine. J. G. Hamilton; *J. App. Phys.* **12**, 440–460 (1941).

Exploration toward the limit of utilizable pressures. P. W. Bridgman; *J. App. Phys.* **12**, 461–469 (1941).

Maupertuis, and the principle of least action. J. Fee; *Sci. Mo.* **52**, 496–503 (1941). An interesting history of what is sometimes regarded as the greatest generalization of physical science.

What is philosophy? A. J. Bahm; *Sci. Mo.* **52**, 553–560 (1941).

Suggestions for improving engineering textbooks in which coordinates are used. E. A. Hertzler; *J. Eng. Ed.* **31**, 660–667 (1941). Errors and faulty statements, and their correction.

High school physics for general education. K. E. Vordenberg; *Sch. Sci. and Math.* **41**, 548–552 (1941). Report of a committee of the Central Association of Science and Mathematics Teachers.

The physics teacher faces his problems. J. T. Peters; *Sch. Sci. and Math.* **41**, 559–567 (1941). A review of the educational problems facing the secondary school teacher, with suggestions for meeting them.

A method for making snowflake replicas. V. J. Schaefer; *Science* **93**, 239–240 (1941). An extremely simple technic for preserving snowflakes, frost crystals and similar perishable formations.

Electrical contact resistance. G. Windred; *J. Frank. Inst.* **231**, 547–585 (1941). A review, with an indication of those branches that offer scope for further research.

Measurements of orchestral pitch. O. J. Murphy; *Bell Lab. Rec.* **19**, 143–146 (1941). A study of the frequency variation of the note A in various broadcasts of concert music.

The copper oxide varistor. W. H. Brattain; *Bell Lab. Rec.* **19**, 153–159 (1941). Its preparation and properties. A *varistor* is a circuit element whose resistance depends upon the sign of the applied potential difference.

Physics in the printing and paper-making industries. V. G. W. Harrison; *J. Sci. Inst.* **18**, 103–109 (1941).

Physics and invention. C. F. Hagenow; *Sci. Mo.* **53**, 142–147 (1941).

Electron theory of thermoelectric effects. W. V. Houston; *J. App. Phys.* **12**, 519–529 (1941).

A study of some concepts and beliefs in chemistry and physics. L. L. Ralya; *J. Chem. Ed.* **18**, 364–367 (1941). This study of entering freshmen was motivated by the ideas that (1) there are many scientific concepts and beliefs that are so relatively simple and so significant for lay thinking that they should become a part of the mental equipment of most people, and (2) investigations of specific strengths and weaknesses in scientific understanding should lead to improvement in science teaching comparable to the improvement in language and arithmetic teaching that have already been brought about by studies of a similar character.

IN 1880, at Johns Hopkins, Peirce lectured on Logic under the auspices of the department of Mathematics, of which James Joseph Sylvester was then the famous head. One day Sylvester said to a beloved mathematical student of his: "You have attended Mr. Peirce's lectures. Tell me your impression of them." At some length the student responded that they were always substantial, never trite, often very subtle, frequently so profound or obscure that listeners were unable to understand them, "but," added the student, "Mr. Peirce is certainly a genius." Thereupon Sylvester said impulsively: "Well! If he is a genius, isn't that enough? Isn't it geniuses that we want here?"—Cassius Jackson Keyser, *Portraits of Famous Philosophers* (1939).